

FINDING YIRLINKIRRKIRR: PROTECTING COUNTRY AND EVERYTHING IN IT

COSMOS

THE SCIENCE OF EVERYTHING

ISSUE 101

GOYDER'S LINE

Australia's climate
crystal ball

VECTORIZING IN

Insects conquer
high-school maths

DRUGS 2.0

Can we
prioritise
health over
profit?

WE FEAR IT

THE SCIENCE OF FIRE

WE NEED IT

HOW WELL DO WE KNOW IT?



ELECTRIC CAR MYTHS BUSTED 🔥 TREES GO TECH 🔥 ORANGE UNPACKED 🔥 BEST PHOTOS IN SPACE



► Tech trees

How can a film capture the feeling of standing in an ancient forest? For *The Giants*, a biopic about former Greens leader Bob Brown and the forests he spends his life protecting, the answer was animation. The film drew on the expertise of French animator Alex Le Guillou to build gorgeous sequences of Tasmania's trees. His artistic imaginings were grounded in the work of spatial scientists at the University of Tasmania, who used LiDAR technology to capture myrtles, mountain ash and Huon pines in immense point clouds of data. Le Guillou used these to create animated insights into the many-layered worlds of these forests, including processes unseen to the human eye like water rising through a tree trunk. To find out more, turn to page 98.



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Call & return

I THINK there were mistakes in Mind Games in Issue 99, page 112. The columns are out of order. Am I right?

Paul van Leeuwen

Paul, you are indeed right. Puzzles are serious business and we apologise to all readers out there frustrated by this. To the newsroom's delight, the rotating role of puzzle-tester has now been installed, so we trust the problem won't re-occur.

IN RESPONSE to the article "There could be an Earth-like planet hiding in the Kuiper Belt", I have a suggestion on new naming conventions.

Eventually, NASA is going to run out of ancient deities to name exoplanets after. I would suggest naming planets after influential science fiction characters. For example, we might one day colonise planet Teela Brown (Ringworld).

Larry Chan

I LIVE in Dunedin in New Zealand and we have a Nature Festival that's been going for eight years. I borrowed a *Cosmos* magazine from the Dunedin Public Library and read about the Currency Creek Arboretum and its open day, and that's what persuaded me to visit Adelaide and the Nature Festival here. So now the Wild Dunedin Festival and the Nature Festival are the best of friends.

Suzanne Middleton

Thanks for writing in Suzanne, and thanks for the throwback to "Paddock of Dreams" in Issue 93!

Find out more about both nature festivals at www.wilddunedin.nz and www.naturefestival.org.au.

Great idea, Larry. We're excited already about the binary planets system Uhura/Spock. It made us wonder if any other readers have any suggestions for fun themes for planetary naming? Let us know!

Get in the loop Write to us with comments, complaints or questions at contribute@cosmosmagazine.com

Rewarding times for the *Cosmos* team at the recent Bragg Prize for Science Writing, with the shortlist containing two *Cosmos* pieces: Amalyah Hart's "Model or monster?" (from Issue 95) and Lauren Fuge's "Point of view" (98). Amalyah was one of two runners up to the prize. These stories appear in this year's *Best Australian Science Writing* along with four other *Cosmos* features: "Isolation" by Paul Biegler (95); "Galaxy in the desert" by newsroom journalist Jacinta Bowler (98); "Do we understand the brain yet?" by editor-at-large Ella Finkel (99); and "A universe seen by Webb" by Sara Webb (98).

"Point of view" also won gold in the magazine category at the prestigious American Association for the Advancement of Science 2023 Kavli Science Journalism Awards. It's the first time an Australian magazine has won the award.



Celebrating *Cosmos*: from left, designer Greg Barton; editors Gail MacCallum and Ian Connellan; Amalyah Hart; deputy editor Lauren Fuge; and art director Kate Timms.



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ACKNOWLEDGEMENT

Cosmos is produced on unceded Kaurna land, and we pay our respects to elders past and present. First Nations people are this country's first scientists and we celebrate their connection to this place's deep past and their critical role in its future.

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The Royal Institution of Australia is an independent charity dedicated to connecting people with the world of science. Through *Cosmos* magazine, our free science news site cosmosmagazine.com and free educational resources, we aim to be an inspirational resource centre for the wonders and achievements of Australian and the world's scientific discoveries. We want to spark in all people a desire to be science literate and to make informed decisions about their lives based on rigorously sought and tested evidence.

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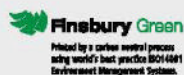


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From the Editors

CAN WE CHANGE OUR MINDS? It's a question that goes to the heart of scientific endeavour, and it's what science does best: asks questions, tests answers, changes path according to the data – and then asks the next question. It's an idea you can take in a lot of directions. Take our cover story from Bianca Nogrady. Fire is as old as time, yet we're still learning about how to shelter from its excesses, and the ways in which it's essential to our country and ecology. Nogrady talks to a diverse range of researchers from modellers to pyrogeographers about what's been learnt and how it's shaping our response.

Next, imagine a world without mathematics. No wheels, no buildings. No printed type. No science. And yet for some, numbers tend to chill not thrill. As Petra Stock points out, Australia is dropping behind in maths skills at a time when it's never been more precious – or sought after vocationally. In yet more mathematical momentum, Robyn Arianrhod takes us on a voyage into vectors. In the 21st century, research has shown birds use them, bees use them – and we're now harnessing them for some thoroughly modern applications.

Also in this issue is a fascinating look at big pharma by Clare Watson. We often take it for granted that the system we have is the only system that works, but as Watson writes, the idea is a fallacy. Drug companies, with their stakeholders and bottom lines, aren't designed to focus on the common good; conversely, a number of models around the world are creating disease solutions affordable to millions. The initiatives work; to enact them all we need is the will.

Changing our minds can also be about listening, and in Arnhem Land, fauna feared extinct is being found in collaboration with First Nations knowledge and connection. Down in South Australia Rachel Williamson reports on what Goyder's Line could tell us about a changing climate – something that in 2023 we can't steer around. It's unavoidably the issue of the age – but our future path is ours to decide. As climate scientists, including Sarah Perkins-Kirkpatrick in this issue, keep reminding us: everything and anything you do can make a difference.

As for us, our minds are on all we've achieved this year (including some recent accolades, see opposite) and on what possibilities can be found in 2024. Thank you for your support, and we hope you'll continue to join us on the adventure.

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DIGEST

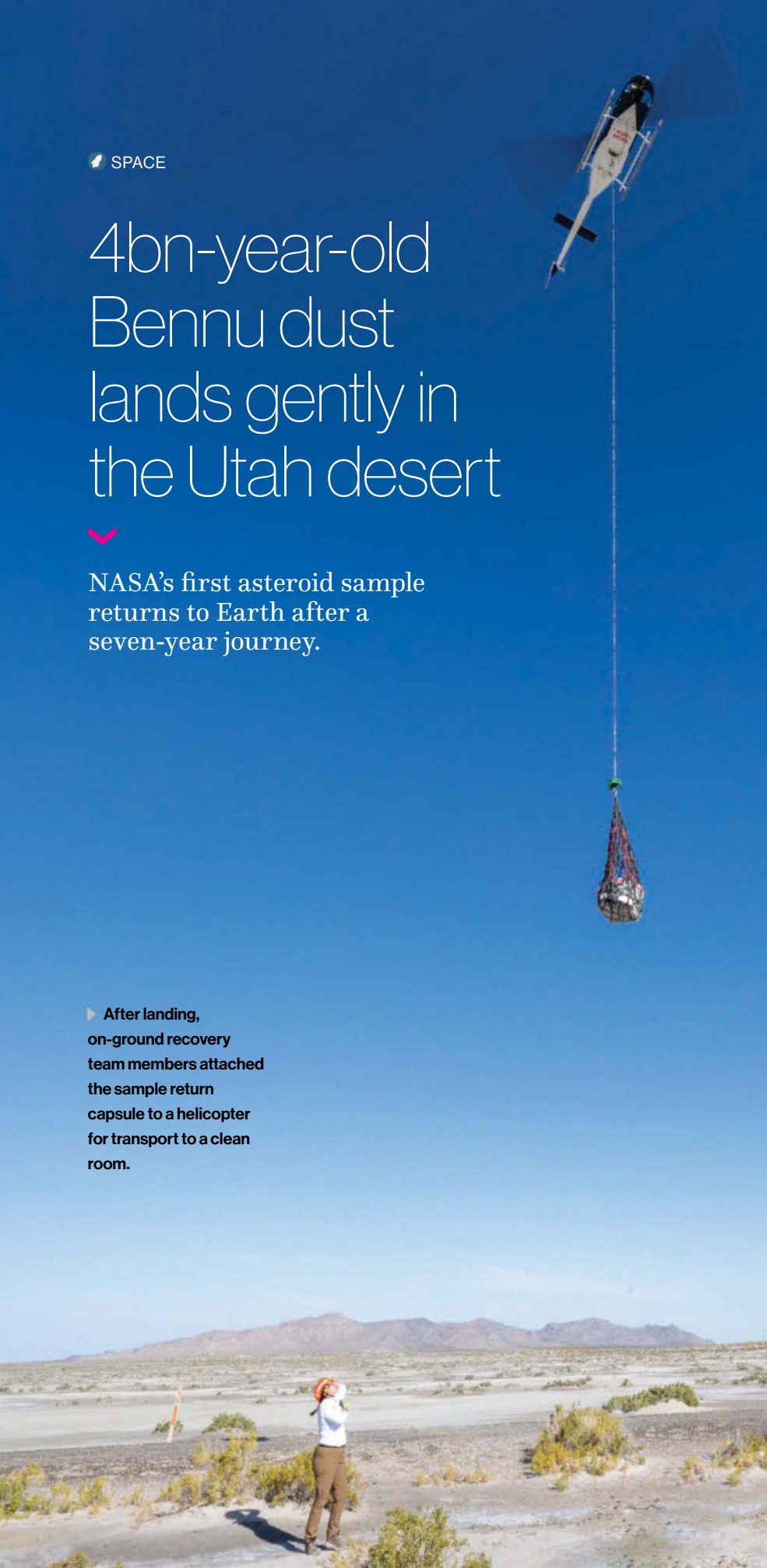
► On Sunday
24 September,
2023, the sample
return capsule of
NASA's OSIRIS-
REx mission
touched down in
the Utah desert.
Inside: part of an
asteroid.



4bn-year-old Bennu dust lands gently in the Utah desert

NASA's first asteroid sample returns to Earth after a seven-year journey.

► After landing, on-ground recovery team members attached the sample return capsule to a helicopter for transport to a clean room.



IT MIGHT have been a scene from a sci-fi movie. Helicopters converging on an object fallen from outer space into a stark, desert landscape. People in gas masks cautiously approaching, checking to see if it's safe.

But science fiction it wasn't. This was the long-awaited return of NASA's OSIRIS-REx mission. Launched in 2016, the spacecraft rendezvoused with asteroid 101955 Bennu in 2018, delicately scooped out material from one of the few flat spots it could find, then headed back to Earth to deliver its cargo to waiting scientists.

The object that landed in the desert was a 45kg capsule released by OSIRIS-REx as it sped by Earth at 45,000km/h, already on its way to its next destination: a hoped-for rendezvous in 2029 with another asteroid, 99942 Apophis.

But the capsule was by far the most important part of the mission. This precious payload entered the atmosphere like a fiery meteor, deployed its parachute and gently plopped onto the mud flats of America's Utah Test and Training Range slightly before 9am local time on 24 September. It landed about 8km east of its target landing zone – a predicted deviation based on weather forecasts of landing-day atmospheric density and wind speed.

"I was really excited," says Mike Moreau, NASA's deputy project manager for the mission. "[The forecasters] told me exactly where it was going to land, and that's where it ended up."

The capsule came down light as a feather, barely denting the soft desert surface, perfectly upright waiting to be collected ... and right near a road that provided a convenient helicopter landing zone. "Boy did we stick that landing," says Dante Lauretta, the mission's principal investigator. "It didn't roll, didn't bounce, it just made a tiny little divot in the Utah soil."

The only glitch was that the first parachute, a small drogue designed to pull out the main chute, may have been slow to fully deploy. But it worked, and – more importantly – so did the main chute.

When Lauretta heard the main chute had deployed, he says, "I literally broke into tears because that was the moment I knew we made it home."

After the capsule hit the dirt, on-ground recovery team members approached with caution. The Utah Test and Training Range is an active military base – plus, the capsule had recently entered the atmosphere at a very high velocity; the heat shield would have hit a peak temperature in the vicinity of 2,800°C (5,000°F). The capsule also contained a battery that might have ruptured and released toxic gases.

As it was, it all went swimmingly. Nobody was blown up, burned or poisoned. Within minutes a member of the team had given the thumbs up and removed his gas mask, and an hour after that, a helicopter carried the capsule to a clean room where it was flushed with nitrogen to drive out Earth air and soon disassembled to retrieve the sample container deep inside it.

The container was then transferred to the Johnson Space Center in Houston and opened. So far, 70.3 grams of Bennu material have been removed, with much more to come as scientists carefully delve into the bulk of the sample. While this isn't the first asteroid sample to be returned to Earth (JAXA's Hayabusa beat NASA to it), it is already the largest.

Portions of the sample will be parcelled out to a wide range of scientists. "We have over 200 researchers using 60 different analytical techniques to interrogate this material," Lauretta says. But much of it will be saved for study in years and decades to come, with methods undreamed of today.

"Those are going to be a treasure for scientific analysis for years and years to come, to our kids and our grandkids, and people that haven't even been born yet," says Lori Glaze, Director of NASA's Planetary Science Division.

The mission is part of a larger NASA project to study asteroids and other small bodies throughout the Solar System, looking for clues to how our Solar System formed – clues that Glaze describes as relating to various chapters of "our origin story".

In the case of the Bennu, she says, "scientists believe that [it] is representative of the Solar System's oldest material, forged in large, dying stars and supernova explosions" – that is, our origins all the way down to the atomic level.



"Bonus sample" in OSIRIS-REx canister

THOUGH THE heart of the OSIRIS-REx sample return canister, called the TAGSAM, has not yet been opened, its exterior contained an unexpected gift.

Scientists found extra asteroid material sitting on the lid – it escaped when other rocks blocked the flap that was supposed to seal the inner container shut. With 70.3 grams weighed, the bonus sample alone is vastly greater than the 5.4 grams returned from asteroid Ryugu three years ago by Hayabusa2.

While the painstaking process of retrieving the main sample continues, the material tested so far proved to contain abundant water in the form of hydrated clay minerals, along with sulphur and magnetites. Excitingly, the sample was also 4.7% carbon by weight.

According to OSIRIS-REx sample analyst Daniel Glavin, "we picked the right asteroid. And not only that, we picked the right sample. This stuff is an astrobiologist's dream."

The water was locked inside a clay mineral called serpentine. The Earth is habitable because of its oceans, lakes and rivers, says principal investigator Dante Lauretta, which exist because "minerals like the ones we're seeing from Bennu landed on Earth 4 billion to 4.5 billion years ago. So, we're seeing the way that water got incorporated into the solid material and then ultimately into planets – not just Earth but probably Venus and Mars as well."

Carbon is also essential for all life on Earth. Scientists want to determine whether asteroids like Bennu could have not only delivered water for our oceans but also seeded the Earth with prebiotic chemicals – the building blocks of life.

The next step is to crush bits of the sample and extract the organics for examination by analytical chemists.

"We'll be making what we call Bennu tea and extracting these compounds," Glavin says. "Stay tuned."



Sample retrieval is slow, as scientists work in a purpose-built clean room.

Malaysian cave art tells a violent story



Dating charcoal drawings reveals their colonial context.



THE CAVE of Gua Sireh, in the Malaysian state of Sarawak on Borneo, features hundreds of drawings of people, many of whom seem to be caught in violent battles.

An international team of archaeologists has now used carbon dating to determine that this art was made from the 17th to 19th centuries, during a period of increasing conflict between Malay elites and Indigenous groups, including the Bidayuh.

“Our work at Gua Sireh indicates this art form was used up to the recent past to record Indigenous peoples’ experiences of colonisation and territorial violence,” says Jillian Huntley, an archaeologist at Griffith University and co-author of the research, published in *PLOS One*.

The team of Australian, Malaysian and New Zealand archaeologists believe this is the first time anyone has used radiometric dating to date Malaysian rock art.



▲ **Mohammad Sherman Sauffi William and Jillian Huntley take samples from the paintings of Gua Sireh on Borneo.**

“It’s challenging to date rock around the world generally,” explains co-author Paul Tacon, also from Griffith.

While radiocarbon dating can accurately date organic matter up to 50,000 years old, most pigments – like the red which is the basis for many Malaysian cave paintings – don’t contain any carbon. Black drawings made in charcoal, however, can often be directly dated. These are found at several sites stretching from the Philippines to Peninsular Malaysia.

Tacon and his colleague Mohammad Sherman Sauffi William, curator at the Sarawak Museum Department, got a research permit to take small samples from Gua Sireh on Borneo. Analysis then showed that the pictures were made from 1670 to 1830, a time which saw increasing conflict in the region.

“There are figures holding what are essentially fighting swords,” says Tacon. “Some of these large figures are surrounded by lots of smaller figures. And we know from the history and ethnography that the paintings that we’ve dated are from a period when there was a lot of violence between Malay elites and the local Bidayuh people, and those on the coasts, the Iban.

“So the nature of iconography, the nature of the images, and the dates that we got, sits perfectly with the historical record of frontier violence at that time.”

William, who is a Bidayuh descendant, says that this information also correlates with the oral history of the Bidayuh people.

“The Bidayuh recall Gua Sireh’s use as a refuge during territorial violence in the early 1800s when a very harsh Malay chief had demanded they hand over their children,” he says.

“They refused and retreated to Gua Sireh, where they initially held off a force of 300 armed men trying to enter the cave from the valley about 60 metres below.

“Suffering some losses – two Bidayuh were shot and seven taken prisoner/enslaved – they saved their children when most of the tribe escaped through a passageway at the back of the largest entrance chamber.”



Powerful progress towards global bushfire prevention.

Research conducted by Victoria University (VU) has the potential to significantly improve bushfire prevention in regional Australia and around the world.

The research highlights how a device developed by VU can reduce the hazard and loss of life that fallen power lines present during fires in heavily vegetated areas. The device detects the broken conductor and shuts down its power before it touches the ground. After trial tests, the research now aims to provide the location of the broken conductor, improving response time to the impacted area, which increases the networks' reliability.

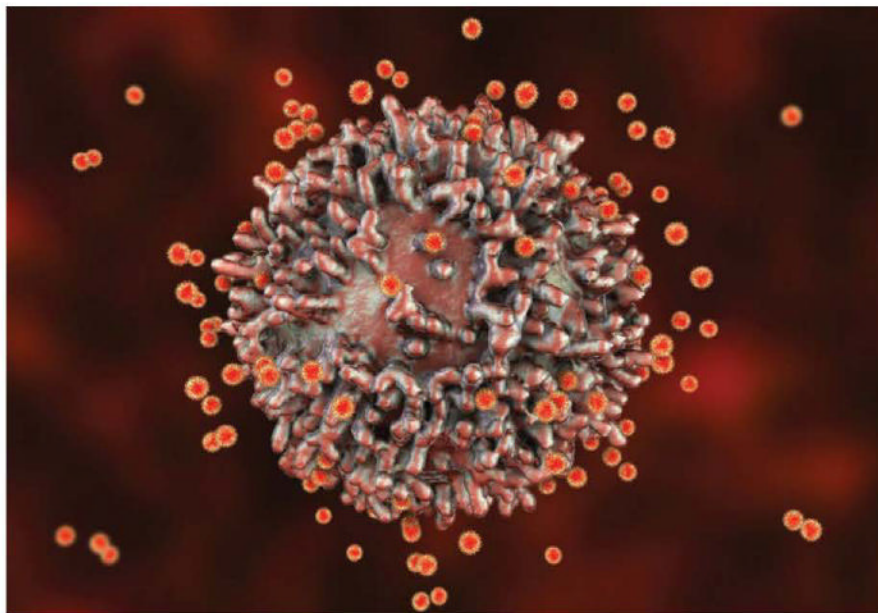
The technology developed by Victoria University's Associate Professor Cagil Ozansoy and Dr Douglas Gomes has great potential to help avert catastrophic and deadly bushfires around the world. Recently, an additional \$464,000 was granted by the Australian Research Council to further this ground-breaking research.



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◀ Conceptual image of SARS-CoV-2 viruses and immune cell.

➤ MEDICINE

Scientists find high killer T-cell response in critical COVID-19 cases

Finding could inform new vaccines.

RESEARCHERS HAVE found an unusual immune response in unvaccinated, critically ill COVID-19 patients that could inform future vaccines.

A study published in the journal *Clinical & Translational Immunology* found cytotoxic T-cell responses in critical COVID-19 cases were far greater than those in mild or asymptomatic cases.

T-cells are a type of white blood cell called lymphocytes. These protect the body from disease by identifying and eliminating malfunctioning or infected cells in the body, including those from viral or bacterial infections, or even cancer.

There are two main types: helper T-cells, which usually have CD4 co-receptors on their surface, and killer or cytotoxic T-cells, which usually have

CD8 co-receptors on their surface. Helper T-cells help activate other cells to fight, while cytotoxic T-cells directly kill infected cells.

This study, led by Sydney University microbiologist Jamie Triccas, analysed T-cell responses in unvaccinated patients with COVID-19 across the full spectrum of disease severity, from mild to critical. In patients with critical COVID-19, the team found an unusually high number of CD4 helper cells – but these cells were actually acting as cytotoxic cells.

“Most of the time, it’s what we’d call those CD8 T cells that are cytotoxic, and the CD4 type that are the helper [cells]. In this case we see it’s cytotoxic CD4 T-cells, which is a little bit unusual,” Triccas says.

“You had this class of T-cells that you don’t normally associate with being

cytotoxic, that were now having this cytotoxic [characteristic].”

While it’s unusual to see a “helper” lymphocyte suddenly pick up its spear and activate its “seek and destroy” mode, it’s not unheard of. Previously, cytotoxic CD4s have been seen in patients with viral infections like HIV, Epstein Barr and dengue.

The concern for patients is that a particularly strong immune response could cause excessive tissue damage.

“Those cells, if they’ve been turned on to have a lot of this cytotoxic type ‘killing’ function, the consequence of that could be that you might get some sort of off-target effect,” says Triccas. “Because these cells are highly activated, they’re making a lot of molecules that activate the immune system and ... you get too strong an immune response and you wind up causing excess damage.”

Patients with more mild and even severe cases had a markedly lower average percentage of cytotoxic CD4s. In critical cases, the team suggests the findings of cytotoxic CD4s might contribute to tissue damage and systemic inflammation associated with death.

While these findings offer little to people at an individual level, they give vaccine manufacturers valuable data when developing next-generation therapies.

“If we want to make new vaccines, or better vaccines, do we have to think about the balance of these types of cells?” Triccas asks.

“Generally the goal of the vaccines is to make a lot of antibodies and I don’t think anyone thinks that too many neutralising antibodies is a problem. But I think you can envisage that too many highly active T-cells could be a problem.

“Our paper is saying that you probably should look quite closely at the different types of cells that are made if you’re making a new vaccine, and then decide: am I generating an immune response that’s balanced enough to not cause any problems?”

Genetically
modified pig
kidney donated
to live human

Two teams of US researchers have successfully transplanted genetically modified pig kidneys into two male patients, both declared clinically brain-dead.

Previous attempts to transplant animal organs into humans have often failed because human bodies reject them.

To overcome this, the first research team raised pigs with 10 genetic modifications, each designed to make the pigs' kidneys more human-like.

They then completed the so-called 'xenotransplant' after receiving permission from the family of the patient – a man in his 50s with chronic kidney disease. After the transplant, the kidney functioned as normal for 7 days before the experiment concluded. The case study is published in *JAMA Surgery*.

Simultaneously, another group of US surgeons kept a pig kidney functioning in a different, clinically brain-dead patient for 61 days. The kidney had only one genetic modification, stopping the production of a biomolecule shown to trigger an immune response that fights back against donated organs.

Bend and snap: tiny origami robots fold to control flight



Agile microfliers can change shape in milliseconds.

RESEARCHERS HAVE crafted miniature origami robots that can fold and shape-shift in mid-air to control their descent.

The tiny, wind-dispersed robots are called microfliers. They are battery-free, light as a pumpkin seed and a few centimetres square in size (similar to a piece of "mini mini" origami paper).

As reported in *Science Robotics*, US researchers designed the robots with origami folds which enable them to snap between two different shapes, each with a different falling behaviour.

"When [they're] flatter the little origami structures have this tumbling descent where they spread outwards with the wind," says co-author Vikram Iyer, an engineer at the University of Washington. "With the other shape they basically fall straight down."

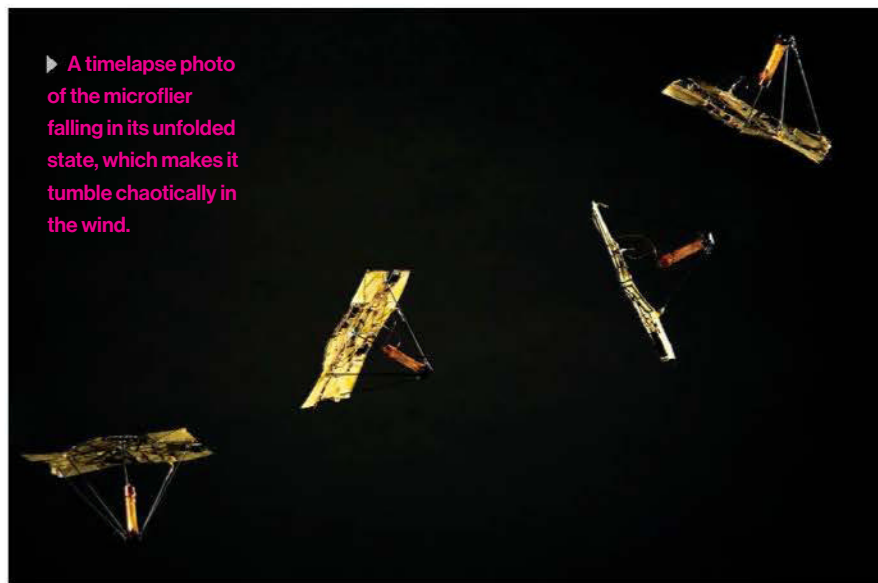
"If we can use these small shape changes to influence how it falls, then we're hoping to get pretty fine-grained control over where these land."

The microfliers are made to carry sensors which measure temperature, humidity and other environmental conditions. They can be released by a drone, automatically dispersing across an area to gather measurements.

A small array of solar cells powers the folding action – triggered by an actuator made from a wire coil and a magnet – along with the robot's tiny onboard computing chip, radio receiver and transmitter, timer and sensors.

The robot's shape change can either be programmed at a given time, pressure or height, or prompted via remote-control.

► A timelapse photo of the microflier falling in its unfolded state, which makes it tumble chaotically in the wind.



› NOBEL PRIZES 2023

PHYSICS

Unveiling the secrets of electrons

Nobel Prize awarded for studying electron movements in the tiniest of split seconds.



◀ Pierre Agostini, Ferenc Krausz and Anne L'Huillier, recipients of the Nobel Prize in Physics.

▶ Opposite, far right: Katalin Karikó and Drew Weissman, recipients of the Nobel Prize in Physiology or Medicine.

THREE EXPERIMENTALISTS have jointly won the 2023 Nobel Prize in Physics for their work in probing the behaviour of electrons.

Anne L'Huillier, Pierre Agostini and Ferenc Krausz helped create the tools necessary to make “films” that capture electrons’ extremely rapid movements inside atoms, by using pulses of ultrafast laser light.

Consider, if you will, hummingbirds. These speedy creatures can beat their wings 80 times a second, so fast that we can’t perceive each beat of their wings with our eyes. But high-speed photography and strobe lighting can capture the flapping wings – as long as the pulses of light are separated by a time shorter than that of each beat. The faster the event, the faster the pulses have to be.

The movements of electrons are like the wings of hummingbirds – only much, much faster. Understanding the world of electrons requires working on the scale of

the attosecond, where an attosecond is one quintillionth – or one billion billionth – of a second. There are more attoseconds in one second than there have been seconds since the Big Bang!

And here lies the problem. The shortest pulse of light that can be produced with a laser is on the order of femto-seconds, which is a thousand times too long for electron movements to be studied. So physicists had to figure out how to work on attosecond scales – not just producing new technology, but also the new field of attosecond physics.

In 1987, L’Huillier – a professor of atomic physics at Lund University in Sweden – discovered that an infrared laser interacting with atoms in a noble gas created overtones. These are wavelengths of light that complete several cycles for each cycle in the original wave, in this case the infrared laser. Theoretically, by combining overtones, shorter and shorter pulses of light could be “built”.

Then in 2001, experimental physics professor Pierre Agostini from Ohio State University built on L’Huillier’s research. He successfully used the effect she discovered to produce and investigate consecutive light pulses that lasted only 250 attoseconds – shorter than previously possible, the shortest flashes of light ever produced.

At the same time as Agostini, Ferenc Krausz – from the Max Planck Institute of Quantum Optics and Germany’s Ludwig Maximilian University of Munich – was working on a different experiment that produced a single light pulse of only 650 attoseconds.

“We can now open the door to the world of electrons,” says Eva Olsson, Chair of the Nobel Committee for Physics.

Since attosecond pulses can be used to test the internal processes of matter, potential applications range from electronics to medical diagnostics.

CHEMISTRY

Size matters: Quantum dots take prize



Planting the seed for nanotechnology.

Moungi Bawendi, Louis Brus and Alexei Yekimov have won the 2023 Nobel Prize in Chemistry for the discovery and development of light-shifting nanoparticles called quantum dots.

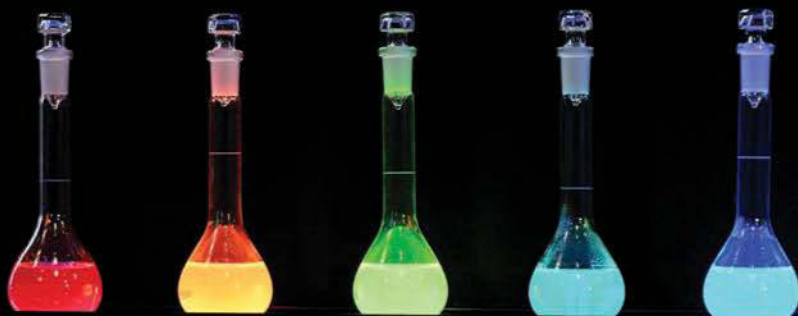
They were predicted in the 1930s and discovered in the 1980s, and yet were harnessed by Roman artisans and beauty stylists thousands of years ago, who used them to play with the colour of glass and dyes. The Lycurgus Cup, for example, appears green in low light but glows red when light passes through it.

Here's the lowdown on the science: The physical properties of a material, like colour or chemical reactivity, are typically determined by its chemical makeup. The atoms that form the material, and how they are arranged, will usually determine the behaviour of the material. But when atoms are arranged into tiny crystals, just nanometres in size, then their behaviour starts to change and size becomes a critical

factor. On the nanoscale, the properties of such particles – called quantum dots – are determined by the laws of quantum mechanics. “Quantum dots have many fascinating and unusual properties. Importantly, they have different colours depending on their size,” says Johan Åqvist, the Swedish chair of the Nobel committee.

The unique behaviour of particles on the nanoscale was predicted as early as 1937, but it took decades before the practical demonstration of these effects were seen. In the 1970s and 80s, Yekimov and Brus separately observed size-dependent quantum effects in nanoparticles in the lab, and later Bawendi studied the ideal conditions to produce quantum dots of the desired size and quality.

The unique optical properties of quantum dots are used today in numerous applications, from LED screens to solar cells to biochemistry.



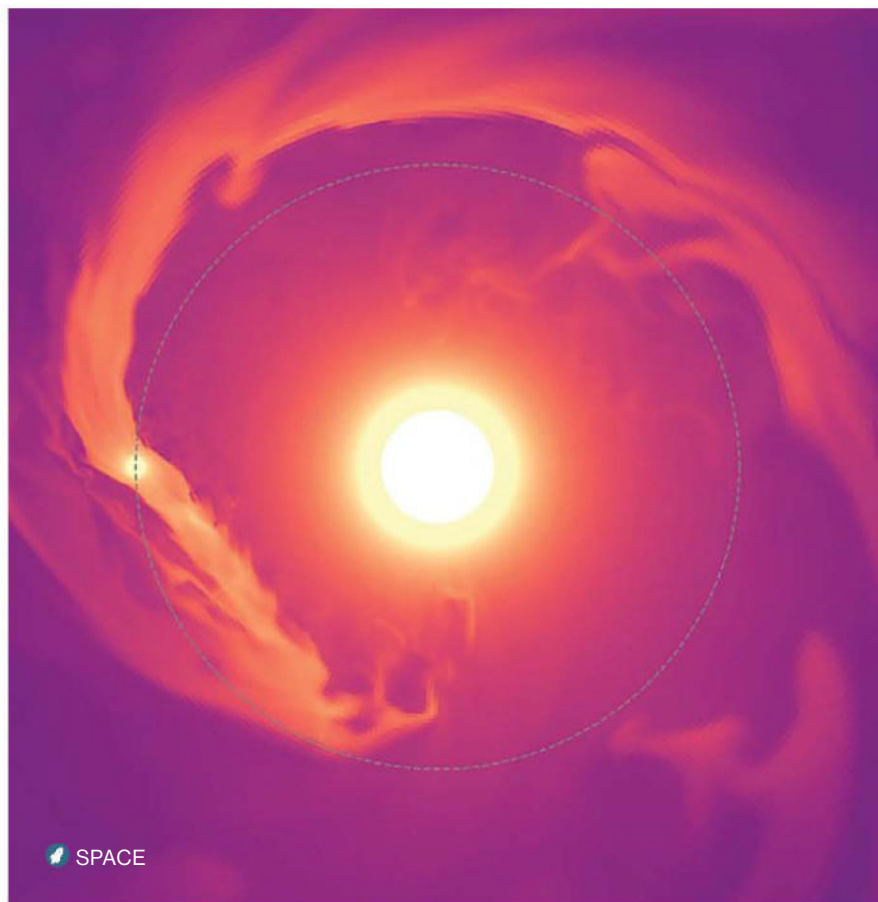
MEDICINE



mRNA vaccine
pioneers recognised
in medicine category

The Nobel Prize in Physiology or Medicine has been awarded to Hungarian biochemist Katalin Karikó and American immunologist Drew Weissman, for research which fundamentally changed our understanding of how messenger RNA (mRNA) interacts with our immune system. Their work laid the foundation for the unprecedented speed with which mRNA vaccines were developed and deployed in response to the COVID-19 pandemic.

Karikó and Weissman have been colleagues at the University of Pennsylvania since the 1990s when their collaborations into synthetic mRNA technology and human immune responses began. Their breakthrough determined that lab-produced mRNAs were treated as foreign entities by the immune system. Further experiments found natural chemical modifications to the body's own mRNA avoided inflammatory response, explaining why unmodified lab versions of mRNA code led to immune reactions.



◀ **Simulation 'slice' through the orbital plane approximating the HAT-P-32 system.**

(slightly more than 3% the distance between Earth and the Sun), HAT-P-32 b has an estimated equilibrium temperature of more than 1,600°C.

Originally discovered in 2004, HAT-P-32 b was confirmed as a planet in 2011. Its radius is more than twice that of Jupiter, but it is slightly less massive.

“We have monitored this planet and the host star with long time series spectroscopy, observations made of the star and planet over a couple of nights,” says co-author Zhoujian Zhang, a postdoctoral fellow in the Department of Astronomy and Astrophysics, University of California Santa Cruz. “What we found is there’s a gigantic helium gas tail that is associated with the planet. The tail is large – about 53 times the planet’s radius – formed by gas that’s escaping from the planet.”

Researchers used three-dimensional computer simulations to help model the flow of the planet’s atmosphere based on data from the Hobby-Eberly Telescope at the University of Texas’s McDonald Observatory.

Astronomers are interested in hot Jupiters because they may help explain a phenomenon known as the “Neptunian desert”: the relative scarcity of Neptune-sized planets, which are an intermediate between the gas giants (like Saturn and Jupiter) and the smaller rocky planets (like Earth and Mars).

“One of the potential explanations is that maybe the planets are losing their mass,” Zhang says. “If we can capture planets in the process of losing their atmosphere, then we can study how fast the planet is losing their mass and what are the mechanisms that cause their atmosphere to escape from the planet. It’s good to have some examples to see like the HAT-P-32 b process in action.”

The scientists hope to survey 20 additional star systems to find more planets losing their atmosphere and learn about their evolution.

Analysis of the planet is published in *Science Advances*.

Hot Jupiter-like exoplanet expels a spiral cloud of helium



Heat of host star evaporates atmosphere of giant planet.

AN EXOPLANET has been spotted releasing huge amounts of helium gas, leaving a spectacular trail in its wake as it orbits a star 950 light-years from Earth.

HAT-P-32 b is losing so much of its atmospheric helium that it has created one of the largest planetary structures yet discovered outside our Solar System.

The planet is known as a “hot Jupiter”: a class of exoplanet close to their stars with searing surface-atmosphere temperatures. Orbiting its host star at a distance of just five million kilometres

“

The tail is large – about 53 times the planet’s radius.”

Dive into the science beneath our oceans

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Focus: Fossils

1

Fossils found in NSW show that a monster trapdoor spider (pictured) – five times larger than its modern relatives – roamed Australia's rainforests 15 million years ago.

2

Ravens lived alongside humans in China hundreds of thousands of years ago, according to fossils unearthed from the Peking Man site.

3

Did you know that there's a 30-million-year gap in Australia's marsupial record? New fossils of an ancient koala will help us figure out what happened.

4

Modelling shows that our ancestors might have been able to hold their own against large scavengers – such as giant hyenas – when competing for carcasses discarded by apex predators.

5

Researchers have found the stomach contents of a fossilised trilobite: soft tissue preserved for 465 million years. Its final meal? Shelled critters: bivalves, crustaceans and more.

6

The discovery of a three-eyed arthropod, dating from the Cambrian period, has shown us an evolutionary road not taken.



NATURE

Aussie first: southern right whale's round trip tracked

West Australian researchers have recently had a whale of a time tracking the return trip of a southern right whale from the state's south coast to Antarctica.

They attached satellite tags to southern right whales (*Eubalaena australis*) before the animals left Albany to head to their southern feeding waters. A year later, one whale – named Nebinyan after a 19th-century Aboriginal whaler – returned to almost the exact location where its journey began, clocking up over 20,000 km.

The trans-Tasman collaboration between marine biologists from the University of Western Australia, Macquarie University and the University of Auckland Waipapa Taumata Rau also obtained tissue samples to compare the genetic profiles of southern rights across the Southern Ocean, including those that migrate along Australia's east coast, New Zealand and South Africa.

? Guess the object

Turn up the heat

Believe it or not, the 19th-century chemist who invented this device is a household name, which is especially familiar to high schoolers. But this contraption is a more complicated version of the ones used in dingy school science labs, with a few extra bells and whistles that give the object a much more *specific* purpose.



We know you can Google it, but where's the fun in that? Tell us what you think it is. The correct answer – and/or the most creative – will be published in our next issue. Send your hunches to contribute@cosmosmagazine.com

High flyers

Guesses for last issue's object spanned over many eras: "Cockpit of the Bell X-1, flown by Chuck Yeager and the first aircraft to break the sound barrier," John de Vry suggested; Aiden Blanchfield thought it was a MiG-25 Foxbat – a Russian fighter plane; Dave Misun guessed the Lockheed U-2 reconnaissance aircraft.

The correct answer came from both Ian Sexton and Mark Starcevic. It's the cockpit of a North American X-15: a hypersonic, rocket-powered aircraft flown by the US Air Force and NASA from 1959 to 1968. Three were built, and they were made to fly high and fast. Over 199 flights, the X-15 crossed the edge of space and set a still-unbroken record for the

highest speed recorded on a crewed, powered aircraft. The aircraft also trained future astronauts – Neil Armstrong among them.

"I grew up in the early '60s and remember news stories about the accomplishments of this aircraft," Starcevic wrote in. "It is amazing what slide rules and brave people can accomplish!"



Ancient tree rings reveal largest ever solar storm 14,300 years ago

Spike in radiocarbon points to extreme space weather.

ANALYSIS OF ancient tree rings from the French Alps has revealed that a massive solar storm – the largest ever identified to date – occurred about 14,300 years ago.

The clue was a spike in radiocarbon level, detected by an international team of scientists investigating ancient tree trunks, known as ‘subfossils’: remains where the fossilisation process is incomplete.

By comparing this radiocarbon spike with levels of beryllium in Greenland ice cores from the same period, the researchers concluded the event was likely caused by a huge solar storm.

The findings are published in Royal Society’s *Philosophical Transactions*.

Lead author Professor Edouard Bard, at the Collège de France and multidisciplinary research centre CEREGE, says



▲ Tree rings of a buried subfossil tree in the Drouzet River, France.

extreme solar events create short-term bursts of energetic particles that are preserved as spikes in radiocarbon.

“Radiocarbon measured in tree rings, used alongside beryllium in polar ice cores, provide the best way to understand the Sun’s behaviour further back into the past,” he says.

Extreme solar storms, called Miyake Events, are known to have occurred nine times in the last 15,000 years. The most recent events occurred in 993CE and 774CE. However, Miyake Events have never been directly measured and remain poorly understood.

“Direct instrumental measurements of solar activity only began in the 17th century with the counting of sunspots,” says Bard. “Nowadays, we also obtain detailed records using ground-based observatories, space probes and satellites. However, all these short-term instrumental records are insufficient for a complete understanding of the Sun.”

The largest directly observed solar storm occurred in 1859, causing massive disruption on Earth such as destroying telegraph machines. A solar storm today on a similar scale would be catastrophic to modern technological society, potentially wiping out telecommunications, satellite systems and electricity grids.

The finding has potentially important implications for global communications and energy infrastructure. Better understanding such events can help humanity prepare and build resilience into these systems.

SPACE

Exoplanet is first found in a quadruple system

A MASSIVE planet, 15 times larger than Jupiter, has been directly imaged, revealing a complex cosmic dance involving four celestial bodies.

The exoplanet was found in a star system called HIP 81208, 477 light-years from Earth.

Astronomers knew that the system is home to three stars: a blue-white star, a red dwarf and a brown dwarf.

But it was not until the European Southern Observatory’s Very Large Telescope in Chile snapped a picture of the system that astronomers noticed a fourth object in the system – a planetary mass body orbiting the red dwarf.

The gas giant has a radius slightly larger than Jupiter, but weighs 14.8 times as much. This means the newly

discovered exoplanet sits right at the border between a planet and a brown dwarf – “failed stars” too small to fuse hydrogen into helium in their cores.

Studying the celestial quartet will help us understand how complex systems like it form and evolve.

The study is published in the journal *Astronomy & Astrophysics*.

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BoM calls it: El Niño and positive IOD underway



Summer of severe heat predicted for Australia.



AFTER MONTHS of waiting for key climate factors to align, Australia's Bureau of Meteorology (BoM) has declared two climate phenomena – El Niño and a positive Indian Ocean Dipole (IOD) – are underway. These will influence temperatures and rainfall for the rest of 2023.

The last years both El Niño and a positive IOD were declared include 2015, 2006 and 1997. Compound events can produce distinct climate patterns, resulting in a strong, widespread drying effect across Australia. Southern Australia can expect warmer temperatures than average in spring and summer. Reduced rainfall is also expected, particularly in eastern Australia. A positive IOD typically drives down spring rainfall across the continent, though not always: in 2012, the east saw below-average rainfall while Western Australia saw the opposite.

The BoM also forecasts more extreme temperatures (including single days and heatwaves), overnight frosts and heightened fire danger across NSW, the ACT, Victoria and SA.

"This year's El Niño is developing during some of the warmest global average temperatures in history, meaning that scientists are still learning how El Niño and its impacts are changing as this event unfolds in a warmer world," says CSIRO's Nandini Ramesh.

◀ **Together, a positive Indian Ocean Dipole and El Niño are likely to cause hot and dry weather.**

Weakening atmospheric circulation could mean longer El Niños

More multi-year El Niño and La Niña climate events might be in our future.

A new study in *Nature* has found that the Pacific Walker Circulation – an air cycle which drives the El Niño Southern Oscillation – has changed over the last 800 years. "The overall strength hasn't changed yet, but instead, the year-to-year behaviour is different," says lead author Georgy Falster from ANU.

Falster's team wanted to find out whether greenhouse gases had affected the circulation, but realised atmospheric aerosols, which reflect sunlight into space, played a vital role too.

"So global warming is pushing the water saturation to be weaker, aerosols are pushing the water circulation to be stronger, which means that on average, they've

just sort of cancelled out to nothing," says Falster.

But some atmospheric aerosols are reducing, which may lead to a weakening of trade winds. The study predicts a slower transition between ENSO phases, potentially leading to multiple El Niño or La Niña years before moving towards neutral conditions. "This year is a good example of that," Falster says.

How will El Niño change in the future?

New research predicts El Niño and La Niña events are likely to get stronger over the next few decades before possibly weakening towards the end of the century.

The predictions are based on simulations using climate models from all over the world, published in *Earth System Dynamics*. Increases or decreases in rainfall due to El Niño or

La Niña events are projected to become more extreme, and these events will tend to be even more concentrated in the Southern Hemisphere summer rather than the rest of the calendar year. The models also predict that the warmest El Niño sea surface temperatures in the tropical Pacific will likely move more frequently from the east towards the central Pacific, and that stronger and longer La Niña events will follow El Niños.

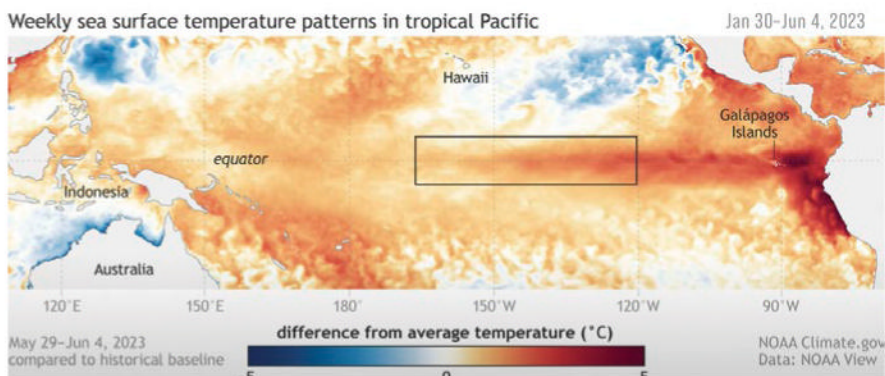
These predicted changes are important because of the impacts El Niño and La Niña events have globally.

How El Niño and La Niña are predicted to change with time is linked to the world's CO₂ emissions pathway – that means, which decisions humans take in terms of carbon emissions will be extremely important in how the events evolve in the future.

Why we won't have a super El Niño this year



But they will occur more often as we heat the world.



MEDIA HEADLINES may be saying the world could be set to face a “super El Niño” this year, but using history as a guide, the likelihood of that is low.

What scientists refer to as extreme El Niños, such as the 1997 and 2015 events, tend not to follow consecutive La Niña events, and we’ve just finished a triple-dip La Niña.

Since 1950, there have been five three-year La Niña events – 2020–2022, 1998–2000, 1983–1985, 1973–1975 and 1954–1956. None of them were followed by an extreme El Niño, and only one was followed by a strong El Niño in 1957.

This is bad news for newspaper headline writers, but better for the rest of us.

During the neutral phase of the El Niño–Southern Oscillation, westward-blowing trade winds pile up warm sea surface temperature water in the western Pacific Ocean, and drive the upwelling of cold, subsurface water in the east along the equator and off the west coast of South America, forming a cold tongue of current extending to the central equatorial Pacific.

Warm and moist air masses rise high into the atmosphere over this western Pacific warm pool, producing rainbands or convergence zones over the western Pacific.

▲ **Transition from La Niña’s cool waters to El Niño’s warm waters in the Pacific in early 2023.**

But during an El Niño, these trade winds weaken and warm sea surface temperature anomalies develop in the eastern equatorial Pacific. During an extreme El Niño, the equatorial eastern Pacific anomalies are particularly large, meaning the sea surface temperature of the water is much warmer than normal.

All the convergence zones congregate in the equatorial eastern Pacific too, generating a massive reorganisation of the atmospheric circulation – for example, the centre of the western Pacific convection moves approximately 18,000 kilometres to the east.

This reorganisation also leads to devastating extreme weather events, like severe thunderstorms and tropical cyclones. For example, during the 1997 El Niño, extreme tropical cyclones killed many in the Cook Islands.

Although this year is unlikely to see an extreme El Niño, other research shows that rare extreme El Niño events are projected to occur more often under global warming.

TECHNOLOGY

This super-fast flood simulator could save lives

As 2023 saw extreme flooding on almost every continent, University of Melbourne researchers have developed a computer model which forecasts floods faster than ever before.

"This ... enables highly accurate modelling to be used in real-time during an emergency," says the University of Melbourne's Rory Nathan. "It's a game-changer."

The model was tested on two Australian river systems. It predicted floods with 99% accuracy on southern Australia's Chowilla floodplain – in just 33 seconds, as opposed to the 11 hours it would take current models. It also spent 27 seconds predicting floods in Queensland's Burnett River system, compared to 36 hours for present models.

The model can also simulate uncertainty in weather forecasts, rather than focusing on the most likely scenario as current models do. This may allow researchers to design more resilient infrastructure by testing thousands of different flooding scenarios.

The results are published in *Nature Water*.



ENVIRONMENT

First recorded total failure of emperor penguin breeding colonies

2023 is predicted to be worse.

THE FIRST case of multiple emperor penguin breeding colonies undergoing total breeding failure has been recorded, and the outlook is just as bad for the upcoming summer.

Last year's reduction in sea ice around west Antarctica is believed to be responsible for the breeding failure in four out of five surveyed emperor penguin (*Aptenodytes forsteri*) colonies, according to the British Antarctic Survey.

Colonies lining the coast of the Bellingshausen Sea were largely abandoned by the start of the fledgling period in December due to sea ice loss, which reached record lows in 2020.

Imagery from Europe's Sentinel2 satellites showed Pfrogner Point, Bryant Coast, Smyley Island and Verdi Peninsula had no signs of a present colony, but one at Rothschild Island managed to persist, potentially due to the unique geometry and iceberg presence in the island's

nearby bay. It's likely chicks in the other four locations did not survive.

The emperor penguin is the largest of the world's 18 penguin species. About 256,500 breeding pairs were estimated to live in Antarctica as of 2019. Breeding in winter, they rely on stable sea- and "land-fast" ice, which forms in winter months to establish successful crèches for their chicks.

Overall, the Bellingshausen Sea – which borders the Antarctic coast closest to Chile and Argentina – saw the loss of at least half of previous sea ice compared to the 30-year average from 1991 to 2020, and complete loss in certain regions. The survey was undertaken in 2022 during what was the worst year for sea ice formation in Antarctica since the beginning of records in 1979.

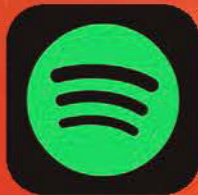
The record won't stand long, with 2023 sea ice already 147 million hectares behind last year's mark.

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Cutting edge

An expert on the structure of disordered solids, **Amelia Liu** is trying to shatter one of the biggest mysteries in science.

When material in a molten phase is cooled very slowly, its atoms have time to organise themselves into a crystal phase. Each atom is in a position of mechanical stability with symmetrically arranged nearest-neighbours; the system attains a new rigidity as the material undergoes a phase transition to a solid.

But if you cool the melt down very quickly, the atoms don't have the opportunity to reach these equilibrium positions. The material still solidifies, but retains the disordered structure of the liquid. This is how glass is formed. And it's a mystery to science.

Glass poses so many challenges. At a fundamental level, physicists don't understand the nature of the glass transition. Phase transitions, where the property of a system changes abruptly, are usually signalled by a change in the order – a “broken symmetry”, as physicists would say.

Identifying these broken symmetries drives a lot of physics research, including into the structure of the early universe and exotic phases of matter like superfluids and superconductors. This research has largely been successful, with the behaviour of many systems fitting into this unifying concept.

However, identifying the order parameter (that is, the degree of order) of the glass transition has remained elusive. It is a strange fact that one of the most ubiquitous and mundane materials is a deep, unsolved problem in physics.

Glasses have fantastic properties that make them an ideal material in many applications. For example, their lack of crystal grain boundaries means they are transparent and will transmit light. Their lack of crystal surface facets also makes them smooth. Glasses are generally quite hard, and good for structural applications.

But they have one well-known failing: they're brittle. So when they are strained beyond their failure point, they will tend to fail catastrophically, with a crack propagating through the whole material.

Crystalline metal alloys like aluminium or titanium aren't brittle like glasses. Glasses can also be made of metals if you can cool the melt down quickly enough. These metallic glasses have improved ductility like crystalline metallic alloys. They are ideal in niche applications, such as MEMS (microelectromechanical systems) and blades on surgical tools. NASA's Jet Propulsion Laboratory is also investigating specialised applications for metallic glasses for the extreme environment of space.

But metallic glasses are difficult to make in large volumes, as the cooling rates to avoid crystallisation and make a metallic glass need to be so high (a million degrees a second). They are also prone to brittle failure.

Glassy phenomena also occur at larger length scales and in different systems. For



Glass poses so many challenges. At a fundamental level, physicists don't understand the nature of the glass transition.


example, microspheres and colloids form glasses, and the behaviour of granular systems like sand share many features with glasses. Other disordered systems where flow can suddenly turn into arrest are partially analogous to glasses – for example, the behaviour of crowds dispersing from a venue, like a sell-out match at the MCG.

I find these phenomena fascinating. At some level, all the challenges of glasses – like their fundamental solid nature, finding good glass-forming systems and improving their mechanical properties – are related to their structure.

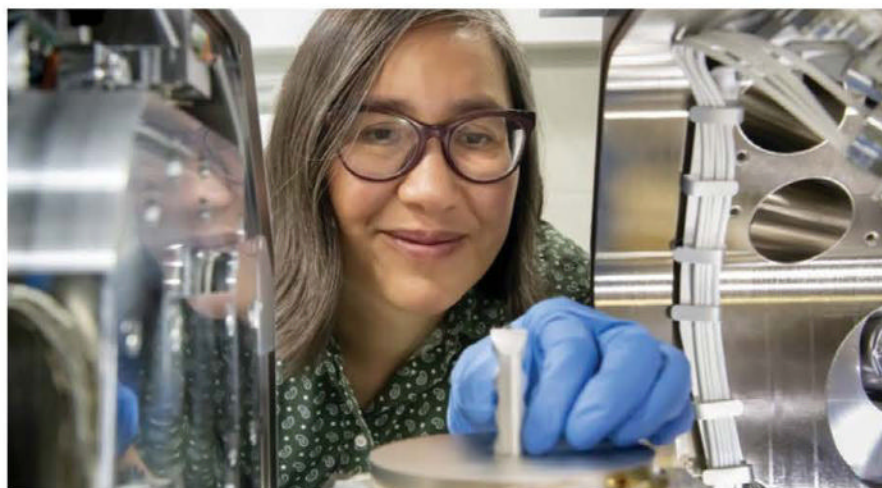
The science of crystallography that determines the structure of crystals, largely through x-ray or electron diffraction, has really underpinned our understanding and development of crystalline materials. But currently there is no routine experimental method that can determine the structure of a glass.

This is where I have chosen to do my research, trying to develop new methods to understand the structure of glasses. I work in small teams of collaborators at local facilities like the Monash Centre for Electron Microscopy and the Australian Synchrotron. These teams are diverse, including experimental and theoretical physicists, chemists, materials scientists and synchrotron scientists. We examine metallic and colloidal glasses with electron and x-ray diffraction.

A major advance we have made is to shrink the electron or x-ray beam down to the size of a nearest-neighbour structural unit in a glass. The subtle angular symmetries of these small-beam diffraction patterns reflect the local structures in glasses. From these, we can extract a wealth of information about the structure of glasses. This new information promises to reveal some of the secrets of glass, but there are many more challenges to overcome.

While grand scientific challenges can be found in the smallest particles and the largest structures in the universe, deep mysteries also reside in very commonplace materials, like glass. 

DR AMELIA LIU is an ARC Future Fellow at Monash University. She received the 2023 John Booker Medal from the Australian Academy of Science for her work on the structure and properties of glass.





2023 is on track to be the hottest year on record. Climate scientist **Sarah Perkins-Kirkpatrick** looks at what comes next – and how to navigate these overwhelming times.

2023.

When I try to think of ways to describe this year, I become stuck. The climate scientist in me gravitates to words such as concerning, extreme, extraordinary. The everyday citizen in me leans towards alarming, shocking, distressing. Both sides believe that 2023 will be a milestone in the Anthropocene.

Perhaps like me, you've been watching extreme weather predictions become observations. Perhaps like me, you've felt horror, frustration, fear or hopelessness. These feelings can be overwhelming, paralysing. But we can – we must – harness them to act. Now more than ever, we need to figure out how to navigate into our uncertain future.

How extraordinary was this year?

We have truly seen some remarkable extreme events these past 12 months.

Antarctic sea ice has declined dramatically over the past few years, and this year huge swathes of winter sea ice failed to form. It reached its maximum extent of just under 17 million square kilometres in early September, almost 9% below the 1981–2010 median. This has severely impacted the breeding cycle of emperor penguins. In 2022, four out of five colonies in the Bellingshausen Sea region experienced catastrophic breeding failure. Worse is projected for 2023.

Meanwhile, the Northern Hemisphere recorded its hottest ever summer by a large margin, with the warmest August following the warmest July following the warmest June. The

global average temperature across these months was 16.77°C, which is 0.66°C above the 1991–2020 average, and 0.29°C above the previous record from 2019 – a huge jump.

Heatwaves swept across the globe from South America to Asia. Research found that the extreme heatwaves seen in Europe and the US, for example, were made 2.0–2.5°C hotter by climate change. Hot, dry conditions contributed to widespread wildfires, too; in Canada an unprecedented fire season burned through 18.5 million hectares, smashing the 1983 record of 7.1 million ha.

It therefore comes as no surprise that 2023 is well on track to be our warmest year on record. July and August both surpassed 1.5°C global warming above the pre-industrial average, the first time a monthly temperature anomaly this high has occurred during the boreal summer.

And remember: these monthly excursions beyond this ominous threshold are occurring when the annual temperature change is only at 1.1°C above pre-industrial levels. Once we reach 1.5°C global warming, monthly excursions will be higher again, bringing with them even more unprecedented and unfathomable extremes.

Stay with me here. We don't have the luxury of looking away.

The record-tumbling extremes of 2023 are the result of the concoction of both climate change and El Niño. While the triple-dip La Niña from 2019 to 2022 brought its own barrage of regionally dependent rainfall-related extremes, it gave a reprieve from ever-climbing global temperatures and record-shattering heat events. Our last hottest year on record was 2020, tied equally with 2016.

But the reprieve was short-lived. The cooling mask of La Niña has lifted, allowing climate change to rebound to its previous trajectory.

In future years, we will not need the combination of El Niño and climate change to reach the thresholds we have in 2023. In future years, climate change will be more than capable of doing that itself.

Many say we are entering a “new normal”, but both personally and professionally, I cannot stand the term. Normal implies stability, a constant state resistant to expected but short deviations.

There will be nothing stable about our future. Even if miracles were to happen and we stabilised global warming at 1.5–2°C, changes in many systems would continue for years, decades, centuries, as the climate slowly finds its new equilibrium. Our atmosphere is a potent soup where so much of the carbon dioxide and other greenhouse gases we have emitted are stored; many will stay there for hundreds of years.

Additionally, our hopes of achieving stabilisation at 1.5–2°C are fading at lightning speed, especially as we are still struggling with our addiction to fossil fuels. And we do not know all of the feedback loops and irreversible tipping points that will ensue. Any description of a “new normal” is folly at best, lethal at worst.

This truth hurts, a lot. It’s easy to feel overwhelmed by the weight of this knowledge. How do we cope with a climate that is forever shifting towards an uncertain future? What chance do we have when so many changes are already locked in, and when, even under the best-case scenario (let alone the most realistic one) things will certainly get worse before they get better? What do we say to our children when they ask why they are facing the flames of a fire they did not ignite?



Sarah Perkins-Kirkpatrick is a climate scientist specialising in extreme events, focusing on heatwaves and event attribution. She is an Associate Professor at UNSW Canberra, and a chief investigator on the ARC Centre of Excellence for Climate Extremes.

What is to be done?

Let’s not mince words. If we call it for what it is and resist the notion of a new normal, then there is hard work ahead, for all of us. But there is good news here: it’s not too late to act. Every molecule of carbon dioxide we stop from being burnt now matters. Every molecule that stays in the ground will give our children the cleaner, brighter future they deserve.

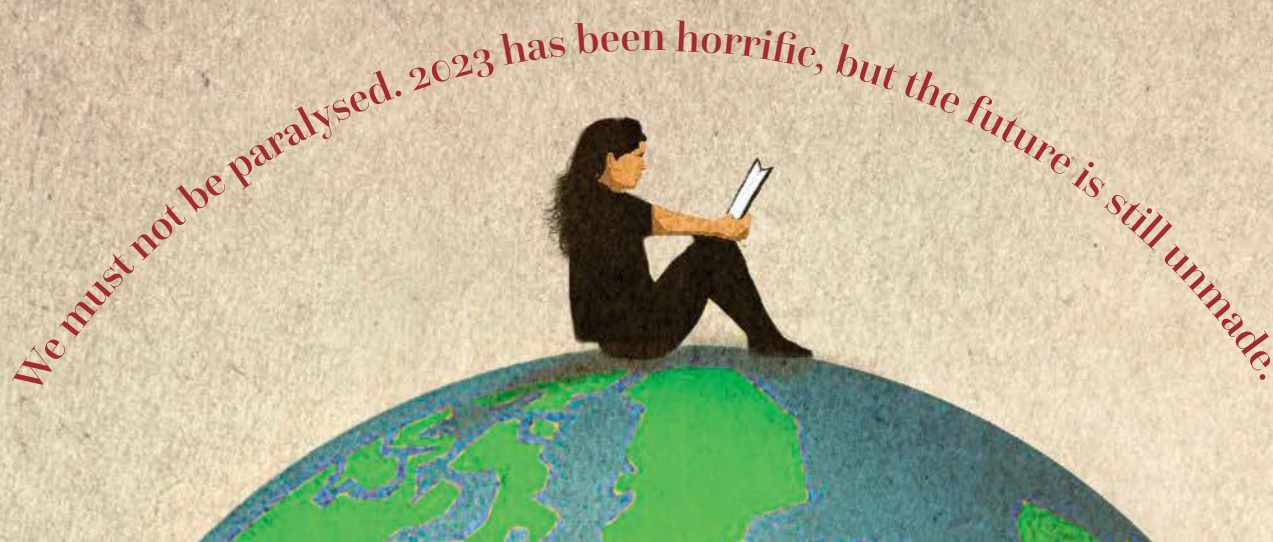
It is imperative that we eliminate our fossil fuel emissions. While progress has finally moved in the right direction in recent years, delay in action over the decades means that we have so much work to do in such a short time. It is incredibly overwhelming.

But another hard truth is we must do more. The climate is already changing, and so we must not only eliminate our emissions but also prepare ourselves for what is to come.

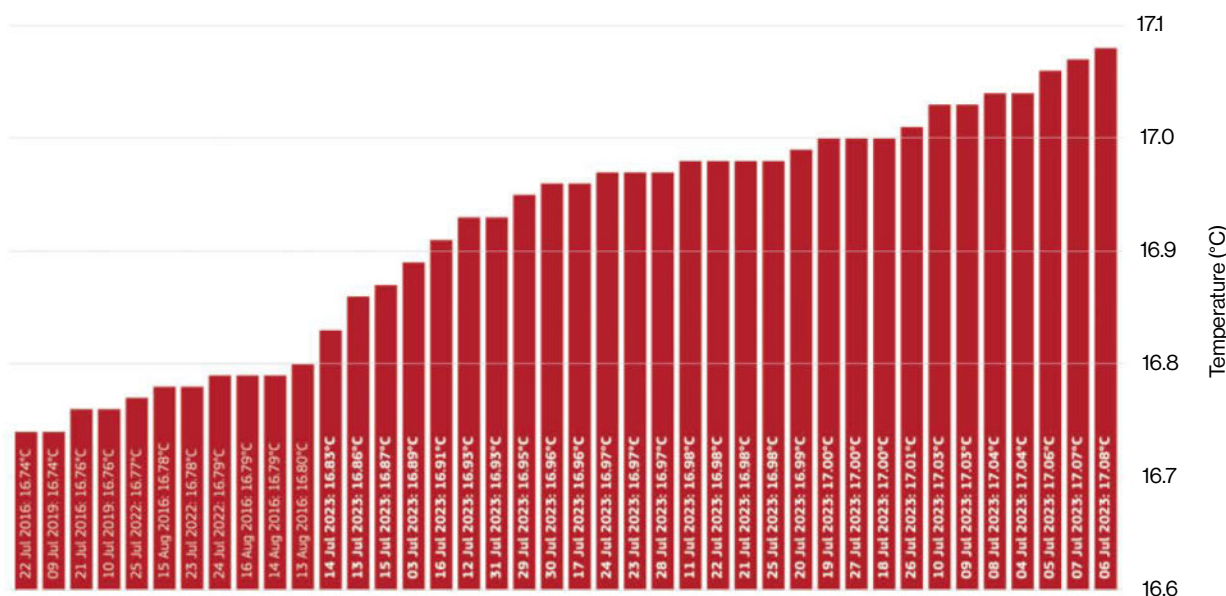
We must ask ourselves: How can we help our medical systems cope with the influx of ailments associated with the effects of heat stress on human health? How can we bolster our communities against the impacts of more intense wildfires? Can we design our infrastructure to withstand more extreme rainfall and floods? Can we shield our economy – and especially our farmers – against more severe droughts?

There is, however, a silver lining. We already hold much of the critical knowledge we need to build our future, thanks to the work of my colleagues around the world. We have a solid understanding of many different future scenarios – we know, for example, that heatwaves scale with global warming; we know both droughts and extreme rainfall will become worse as climate change intensifies; we know the wildfire seasons will become longer with more severe fire weather.

The collective wisdom of many thousands of climate scientists can help prepare us. We have



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everything we need to build resilience into our lives, communities and systems.

The problems we face may seem insurmountable, even crushing. It is a very human response to be stunned by what is to come and fearful of our future. But fear is paralysing. Fear is useless. Instead, at the very least, we need to be angry.

Be angry that the voices of experts have been ignored for decades. Be angry that merchants of doubt have held up progress for their own vested interests. Be angry that our leaders haven't done enough. And be angry for our children, who might not fully comprehend the reality of what lies ahead of them.

But don't just sit there seething. Be motivated by your anger to help change the course we're all on. Be productive.

Like everyone else, I feel the weight of the future. At times, as a climate scientist, perhaps I feel it more than most, when my efforts and those of my peers have amounted to nothing – no change, or meaningless, greenwashed pseudo-changes. It is frustrating, infuriating. It always angers me, but I refuse to let it overwhelm me.

Instead, I channel my anger into action.

At a personal level, my family has made choices in our lifestyle around things like rooftop solar, an electric car and diet to help reduce our carbon footprint.

At a professional level I've ended up not following a traditional academic career. Instead, I am also a communicator, and continue to be openly frustrated about the lack of progress – particularly here in Australia – and how much

This chart is from the [Copernicus Climate Change Service](#), which is part of the [European Centre for Medium-Range Weather Forecasts](#). Its ERA5 contains data from 1940 onwards. It now collects readings from the Earth on a 30km grid, analysing the atmosphere using 137 levels from the surface up to a height of 80km. According to ERA5, all July 2023 days from the 3rd were hotter than the previous day record of 16.80°C, from 13 August 2016.

this is slowing us all down. I try and hold our leaders, peers and even myself accountable so we don't become complacent. So that we all strive to achieve the best possible outcome – less carbon in our atmosphere.

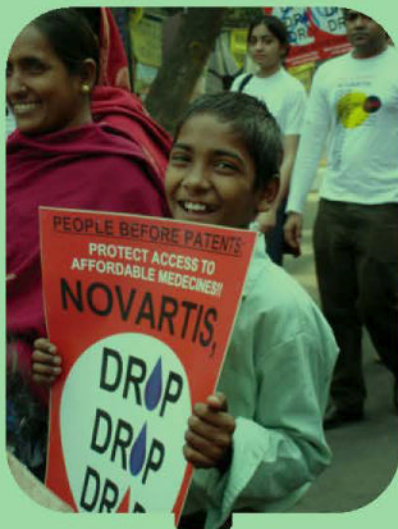
Action can take many more forms. Educating ourselves about what the future holds. Educating those around us, casually yet consistently. Making better choices about what we buy at the supermarket and where we get our energy. Designing our homes and our communities to withstand more prolonged and severe extreme events. Making sure ourselves and our families are prepared in the immediate lead-up to predicted extreme weather events. Divestment of our personal funds away from fossil fuel portfolios. Marching for climate justice. Direct action against fossil fuel extraction. Continuously calling on our leaders for stronger and effective mitigation and adaptation policies.

It all counts. All of it. And if you don't think you can do this all at once, that's okay. Do what you can for now, and do it well. Make a plan for the future where you can entwine more proactive measures into your life. And teach your children what to do, so they don't repeat our mistakes and those of the generations before us.

We must not be paralysed by our latest glimpse into the future. Our 2023 has been horrific, but the future is still unmade, and it is malleable. We still have the agency to make real change. Standing by and hiding behind the farce of a new normal is unacceptable to me – and I hope to you, too. 🍷



Doing



drugs

Does our current drug research system work? Protesters say no. In 2015, Médecins Sans Frontières (MSF) dumped U\$17m (top left) – the amount Pfizer earned each day for its pneumonia vaccine – in fake notes outside Pfizer HQ. Indian protests have successfully campaigned to “Drop the case” and allow access to generic medicines (above right). Other models exist in MSF’s work (top right); at the not-for-profit Mario Negri Institute for Pharmacological Research (opposite top and bottom); the not-for-profit Drugs for Neglected Diseases initiative (DNDi) (opposite middle); and Australia’s ASAVI initiative (right).





What could pharmaceutical R&D look like if Australia – and the world – prioritised public health over profit?

Clare Watson reports.

differently



When pharmaceutical giant Johnson & Johnson got the tick of approval for its drug bedaquiline on the last day of 2012, a new chapter of tuberculosis treatment began. Bedaquiline was the first antibiotic developed for the bacterial disease in nearly 50 years – a breakthrough millions of people across Asia and Africa had been crying out for.

A decade later, bedaquiline has become a latest flashpoint in the searing debate about affordable access to life-saving medicines. Knowing its main patent for the drug would expire in July 2023, Johnson & Johnson sought to extend its monopoly by enforcing secondary patents for an ever-so-slightly altered version in more than 65 countries.

India took a stand. Its Patent Office rejected the company's application in March 2023, following a four-year global campaign agitating for fair access to the drug. Then, in July 2023, a historic deal permitted non-profit organisation Stop TB Partnership to supply cheaper generic versions of bedaquiline to 44 low- and middle-income countries.

While some countries with the highest burden of tuberculosis aren't covered by the agreement, those that are will be able to buy the drug at half price. The Stop TB Partnership estimates that by the end of 2024, more than 51,000 extra treatments could be purchased with the cost-savings.

The deal is a small concession from a pharmaceutical giant that has reaped the benefits of market exclusivity for a decade, and experts say it's long overdue. "It raises the question, why couldn't this have been done earlier?" asks Diego Silva, a bioethicist at the University of Sydney concerned with infectious diseases. "We didn't need to get to the eleventh hour of a patent expiring for this outcry to happen."

The story of bedaquiline is just one example of an industry that has long prioritised profit over public health. Companies argue that sky-high prices are necessary to fund research and development (R&D) into new drugs, but the data doesn't back up this claim. Plus, researchers have repeatedly exposed the pharmaceutical industry's profit-driven motives that shape its clinical trials, skew its drug development and inflate drug prices.

But does it have to be this way? What – or where – are the alternatives?

Around the globe, a few initiatives are going against the grain of the for-profit pharmaceutical industry, instead prioritising neglected diseases, refusing to patent their drug discoveries and funding research that puts public health first. Their work to develop new medicines for a fraction of the cost shows that other models of drug development are not only possible – they're succeeding.

So how do they work, and can we bring these ideas home to Australia?

Fact-checking R&D spending

In a global industry that spent US\$141 billion on R&D in 2015, it's hard to get a clear picture of what it actually costs to develop a drug. "Drugs are expensive to produce, but part of the problem is we're not entirely sure just how expensive it is," Silva says.

The industry isn't known for its transparency. Companies protect their research products with a thick web of patents, and in financial reports they tend to average out their R&D spending across the drug development pipeline.

Researchers like Joel Lexchin, a pharmaceutical policy researcher at York University in Toronto, Canada, analyse the practices of drug companies based on what data is publicly available. It's enough to see trends emerge. "R&D gets sacrificed to share prices," Lexchin says bluntly.

While companies do bring to market some truly innovative medicines – like bedaquiline – their business model has changed. Where once they would reinvest profits into R&D, Lexchin says the world's largest companies now spend more money on marketing their products, buying back their own stocks to lift share prices and paying shareholder dividends.

Health economist Aris Angelis and colleagues laid out the costs in the *British Medical Journal* in early 2023. Based on financial reports from 1999 to 2018, the 15 largest pharmaceutical companies spent nearly twice as much on "selling, general and administrative activities" as they did on R&D: US\$2.2 trillion compared to US\$1.4tn over 20 years. Most of those same companies spent US\$577bn on share buybacks and dividends from

"Drugs are expensive to produce, but part of the problem is we're not entirely sure just how expensive it is."

2016 to 2020 – US\$56bn more than R&D during that time, according to a 2021 US government drug pricing investigation.

Rather than investing in discovery research, large companies have also taken to buying up small start-ups that have done the hard yards developing new candidates. For instance, US biopharmaceutical company Gilead Sciences didn't discover sofosbuvir – an antiviral treatment that transformed hepatitis C care a decade ago. It bought the drug from a start-up for US\$11.2bn. According to a US Senate inquiry, Gilead recouped nine-tenths of that amount in its first year of selling the drug. "That's the model drug companies are using these days," Lexchin says.

The industry claims to be innovating new medicines, which are priced to recoup research costs and offset other failures. R&D budgets of the 14 leading pharmaceutical companies grew in the two decades to 2018.

But a 2021 systematic review of 19 studies found that companies are spending more for each new drug they produce; in other words, pharmaceutical R&D has become more inefficient over time. Another peer-reviewed study traced this decline back to the 1950s.

Research shows that clinical trials are getting longer and more complex, and failure rates in drug development are rising as the industry pursues high-risk, high-reward medicines. Just one in 10 drugs that entered early-stage clinical trials between 2003 and 2011 got approved.

Drug developers also can't learn from their competitors' mistakes, because their work is shielded by patents and companies tend to



Without access to generic drugs, the treatment regimen for extensively drug-resistant tuberculosis (XDR-TB) would be prohibitively expensive. A South African woman (below) displays her daily XDR-TB oral dose.

suppress negative results, so each sinks money into well-trodden paths that lead to repeated failures. For instance, a 2023 study in *JAMA Network Open* found that starting in the early 2000s, drug companies spent US\$1.6bn–2.3bn on 183 cancer trials – involving more than 12,000 patients – to test 16 drug candidates for a popular cancer target. None were approved for treating cancer.

Pharmaceutical companies are also quick to abandon a drug candidate if business priorities change, Lexchin says. The result: companies are outlaying more money than ever before for fewer new drugs – so when they do hit on a breakthrough, patients are paying the price.

The most lucrative medicine on the market, prior to the COVID-19 pandemic, was a treatment for rheumatoid arthritis called adalimumab. Its manufacturer, AbbVie, spent an estimated \$US14.7bn on R&D, then grossed 10 times as much globally after the drug's approval in 2002. Researchers estimate that this income translates to the company netting an eye-watering US\$110bn in excess profits – over and above what would be considered a fair margin for the amount it spent on developing, producing and marketing the drug.

Those kinds of blockbuster drugs are a costly exception. According to economists at the Tufts Center for the Study of Drug Development in Boston, it costs US\$2.6bn to bring one new medicine to market. This includes lab research and clinical trials, but also accounts for other drugs that don't make it through to approval and other financial losses.

But leading pharmaceutical policy researchers have labelled that US\$2.6bn figure an inflated estimate, pointing out that it's based on confidential data on just 106 drugs from 10 pharmaceutical companies that no one can independently verify.

Subtract the tax breaks companies received and account for the fact that only the costliest 20% of drugs were included in the analysis, and researchers have revised the number to about one-tenth of the industry's claimed total. Other more recent analyses of publicly available data have found that on average, the development of one drug costs less than one-third to about half as much as the Tufts estimate.

What's worse is that the majority of newly approved medicines hardly improve on existing drugs, if at all, says Barbara Mintzes, a

pharmaceutical policy researcher at the University of Sydney. Mintzes calls them “me-too” drugs: new formulations of old compounds that provide little advantage over current drugs but which serve to prolong patent protection.

Patents are designed to reward drug developers for innovating new products, giving them exclusive rights for a set period of usually 20 years. However, few new drugs are truly innovative. More than half of new drugs are no better than existing treatment options, according to yearly investigations from French organisation Prescrire International. Another 15% of approved drugs are actually worse; either less effective or poorer safety-wise, says Mintzes.

“When many new drugs do not offer any therapeutic gain to patients, the only beneficiaries are the companies that are marketing them,” Lexchin remarked in a recent commentary in the *Journal of the American Medical Association*.

So, if pharmaceutical companies aren't as innovative as we've been led to believe, and if the innovation they do provide comes at such a high cost, is there another way?

Exploring the alternatives

Since its inception in 2003, the aptly named Drugs for Neglected Diseases Initiative (DNDi) has developed a dozen treatments for six deadly diseases – with no labs and for a fraction of the industry cost.

DNDi was founded by medical humanitarian organisation Médecins Sans Frontières (MSF) in collaboration with research institutes in India, Brazil, Kenya, Malaysia and France, after MSF realised it often didn't have the medicines it needed to save lives.

The initiative focuses on advances in patient care for neglected tropical diseases such as dengue fever, malaria and leishmaniasis. These collectively affect nearly 2 billion people worldwide, yet represent only 0.5% of the more than 56,000 candidate products currently in commercial development.

DNDi operates like a virtual biotechnology company. It contracts industry collaborators and academic partners to conduct specific studies at each stage of its drug development pipeline, funded by in-kind donations and philanthropy. For 12 years, Australian-born medicinal chemist Robert Don was at the helm of DNDi's drug discovery pipeline. Patients were front of mind in every research phase, and “part of every decision we made”, Don says.



55%
of households
affected by TB in
low- and middle-
income countries
spend more than
20% of their
income on TB
treatments.

South African protesters (above) played a key role in the Fix the Patent Laws campaign, co-led by MSF. Propelled by the high cost of anti-retroviral therapy (ART) drugs for HIV, the campaign created political pressure that led to huge price drops for ARTs.

One of Don's proudest achievements sums up the initiative's mission. DNDi developed a drug for African trypanosomiasis (also known as sleeping sickness), an often-fatal parasitic disease. The medication isn't registered yet but may one day replace the existing treatment, melarsoprol, which has to be injected over weeks to months. "Patients would flee the clinic because it was so painful," recalls Don. "We finally got that down to a single pill that had the same side effects as an aspirin."

After two decades in operation, DNDi estimates it spends US\$4 million–\$34 million to develop and register treatments that combine or repurpose existing drugs. Developing an entirely new chemical entity costs US\$63m–\$200m. At its most expensive, that's still 13 times less than the industry estimate.

DNDi's Eastern Africa office supports R&D projects in the region, like the Leishmaniasis East Africa Platform in Sudan. This initiative strengthens clinical research capacity for the neglected tropical disease, as well as serving as a training base and facilitating and evaluating new treatments (below).

improvements in patient care, which are more evident in smaller trials, and smaller trials with fewer patients help to keep costs down.

DNDi also rarely patents its discoveries. To ensure equitable, affordable access to its medicines, the initiative stipulates in its negotiations with drug companies and research partners that their products must be free of any restrictive patents and sold at minimal cost, in all endemic countries, regardless of income levels.

Sharing is caring

DNDi stands in stark contrast to the pharmaceutical industry, but it's not the only alternative model. In Europe, Italy's Mario Negri Institute also prides itself on making its research accessible.



Those new chemical entities come from trawling through the huge libraries of chemical compounds that pharmaceutical firms amass. "It took us years [of negotiations] to break in with the first company," Don says.

But once DNDi was granted access, its scientists could screen thousands of chemical entities using robotic assays to see if any were effective in killing pathogens grown in lab culture dishes. They only pursued a promising drug lead if it could be made as tablets, which are easier and cheaper to distribute in remote, humid regions.

Given the diseases it targets, DNDi runs clinical trials in some extremely challenging environments, crossing rivers and rainforests to reach remote clinics in Africa, Asia and the Americas. But their trials are made somewhat easier by the fact they generally aren't looking for incremental improvements between look-alike drugs as pharmaceutical companies do. DNDi seeks clear

Founded in 1963, the Institute was the idea of Italian pharmacology researcher Silvio Garattini, whose working-class background led him to envision a medical research institute devoted to the public interest. He sold local philanthropist Mario Negri on the idea, and it came to life.

Based in Milan, the Institute aims to improve health with independent, transparent science. It never patents its discoveries, and all its findings are publicly available – including failures. It eschews placebo-controlled trials, instead designing trials to test if new therapies improve on existing treatments. It also investigates harmful side effects that might otherwise go unreported.

Just like any other research organisation, Mario Negri pieces together government grants, industry funding and public donations to fund its work. However, it maintains staunch independence from the pharmaceutical industry and governments by ensuring no funding source

amounts to more than 10% of its annual budget. This allows it to pursue research, design trials, analyse data and share its findings freely.

“Open sharing of science can lead to advances for all of us much more quickly. We certainly saw that during the pandemic,” Mintzes says. “The Mario Negri Institute is an example that that kind of model can exist and actually flourish.”

Where DNDi focuses on select neglected diseases, Mario Negri has a wide-ranging program that tackles some of the biggest health problems of our time, including cardiovascular disease, cancer and neurodegenerative diseases. The Institute also holds the manufacturing industry and governments to account through investigations of environmental pollution and contamination.

It’s also beating the pharmaceutical industry at its main game: large-scale clinical trials. In the 1980s, Mario Negri ran some of the first “mega-trials” in medicine, which revolutionised clinical trial design. The first of those trials showed an inexpensive treatment administered quickly could prevent deaths from heart attacks. The trial involved nearly 12,000 patients across the Italian healthcare system, yet it was planned, conducted and published in under three years. These days, Mario Negri can run trials at one-tenth of the cost per patient of standard industry trials.

“When many new drugs do not offer any therapeutic gain to patients, the only beneficiaries are the companies that are marketing them.”

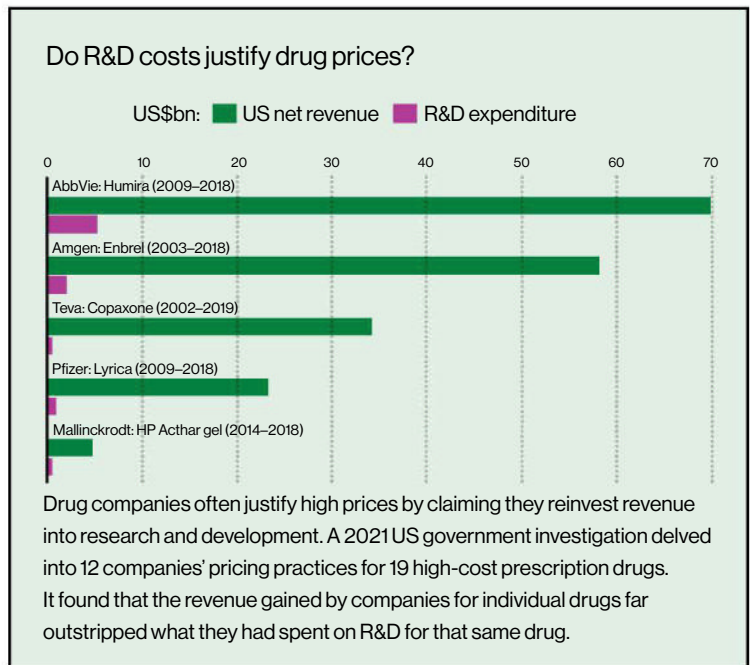
Subscription medicine

We aren’t short of options to change the way we approach drug development. There are plenty of other levers that governments could pull to reorient clinical research towards the areas of greatest need, to prioritise public health over profits.

India is a prime example: its interpretation of patent laws has enabled the country to reject patents from pharmaceutical companies for drugs that do little to improve on existing therapies on multiple occasions.

Before it joined the European Union, Norway also had similar laws to ensure approved drugs were either more effective, easier to take or had fewer side effects than available treatments.

Lexchin says Australia could likewise change its patent laws and tighten up drug regulations to only permit drugs “that really make a difference”. However, the pharmaceutical industry wields strong influence over many national governments



and drug regulators. The industry sustains huge parts of national economies in countries like the US, and largely funds regulatory agencies through user fees. As Mintzes says, it would take “quite a bit of bravery and innovative thinking to bring in these kinds of policies”.

Although Australia only represents a tiny slice of global drug spending and is too small to influence the research interests of the pharmaceutical industry at large, we’re a wealthy country and could steer R&D by channelling more public funding into specific areas of national need.

“Pharmaceutical companies don’t exist without research that is publicly funded,” the University of Sydney’s Silva points out. “R&D isn’t just the moment when a compound enters phase I testing.” It starts long before that, in university labs and research institutes. Reorienting the R&D pipeline begins with adequate funding for basic science, and in Australia research funding has stagnated over the past decade, reducing the likelihood of chancing upon new drug candidates.

Lexchin agrees that increasing public funding, especially of clinical trials but also of early-stage research, could yield better outcomes. “The public sector plays a much larger role than is currently recognised,” he says.

In fact, 25% of new drugs originate in the public sector – and those drugs have more therapeutic value than the ones coming from industry. Take bedaquiline: researchers estimate that the public sector invested US\$455m–\$747m in the drug’s development – three to five times as much as Johnson & Johnson spent.

“In many cases, the public will pay twice,” says Mintzes: once for the initial, public investment in a drug’s development, and again when governments subsidise its access because the prices set by drug companies are so high. “We should be incensed,” adds Silva.

Some policy experts argue drug prices should be capped or early access guaranteed if those medicines were developed with large amounts of

“There needs to be pressure from below, from the public, from clinicians and from researchers – and there needs to be political courage from above.”

public funding. High prices can restrict access to medicines in the US or Australia, as much as any other country. For example, when Gilead priced their hepatitis C antiviral sofosbuvir at US\$84,000 for a course of therapy – a blistering US\$1,000 per pill – less than 3% of eligible Americans could access the treatment through Medicaid.

Australia actually had a radical answer to that problem: in 2015, it pioneered a lump-sum payment fee to manufacturers – AU\$1 billion over five years – in exchange for an unlimited supply of seven hepatitis C antivirals, including sofosbuvir. Researchers estimate that the government saved AU\$6.42bn in those five years and treated 93,413 more patients than if they had paid per packet.

This unconventional approach, dubbed the subscription or Netflix model, has since been adopted by the UK to spur innovation in antibiotic R&D, an area of development that has slowed to a trickle, and Sweden is trying out its own subscription program. Time will tell how effective these pilots will be.

Patent swaps are another idea. Pharmaceutical companies would forgo patenting an essential medicine needed in low- and middle-income countries in exchange for a patent extension on a non-essential product sold elsewhere.

It seems unlikely that this piecemeal approach – one patent here, one drug there – will reshape the global R&D landscape, but each of these strategies offers gains in areas of huge need. Progress can come from many small steps, as well as giant leaps.

Bringing it home

If there’s one area where Australia could really take the lead, it would be in the fight against Group A *Streptococcus* bacterial infections. While we’ve made great strides in quashing dengue fever and reducing tuberculosis, group A strep is a different story. It’s among the world’s deadliest pathogens, causing a whole spectrum of illness and disease, from sore throats to flesh-eating necrotising fasciitis. Yet still there is no vaccine.

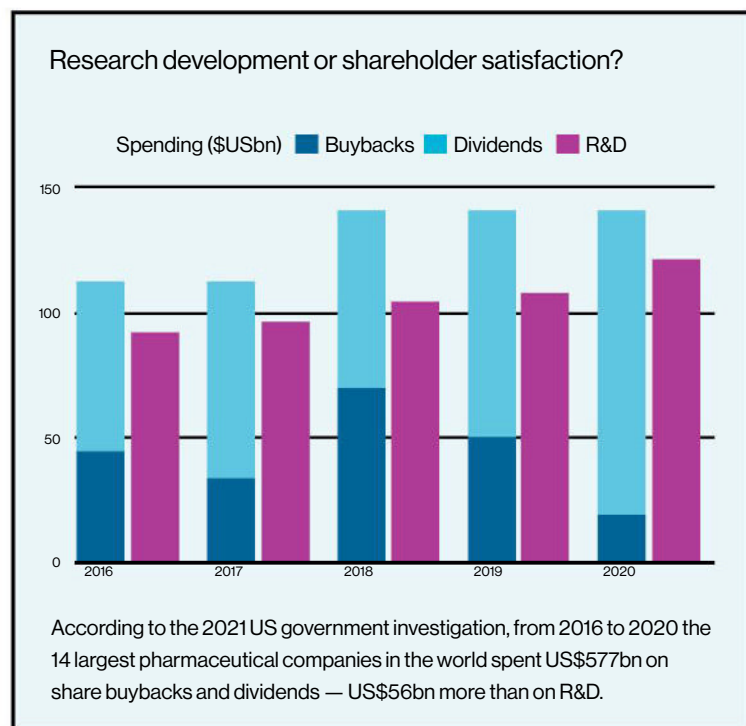
The Australian Strep A Vaccine Initiative (ASAVI) is hoping to change that. The initiative formed in 2019 with an AU\$35m windfall from the Medical Research Future Fund and the clear goal of progressing a strep A vaccine to phase II clinical trials in the next five years.

It’s an example of another R&D model gathering speed: mission-oriented initiatives that “work on a very specific research problem over a defined period of time, deliver results and then move on,” explains Daniel MacArthur, a population geneticist at the Garvan Institute of Medical Research in NSW.

Repeated or untreated strep A infections can permanently damage the heart, a condition called rheumatic heart disease, which leads to heart failure and stroke.

Australia has one of the highest rates of rheumatic heart disease in the world, particularly in one part of our population. “There is such an enormous burden of rheumatic heart disease, particularly in our First Nations people,” says immunologist and ASAVI project lead Alma Fulurija.

Aboriginal and Torres Strait Islander people account for more than 90% of cases of rheumatic heart disease, and are nearly 20 times more likely to die from the condition than the general population.



Fulurija says ASAVI was created as a “new way of accelerating vaccine development” in an area “that perhaps industry wasn’t as interested in”.

Fewer than 12 vaccines are in early development for group A strep, compared to hundreds in the pipeline for HIV, tuberculosis and malaria, she says. (That’s partly because human trials into strep A vaccines were prohibited for nearly 30 years after

The initiative is readying for a phase II trial with its candidate, an Italian vaccine nested in the philanthropic arm of biopharmaceutical company GSK.

Ideally, ASAVI could support more than one candidate with additional funding, so the Griffith University team is continuing its work.



the US drug regulator got spooked by safety data from an early study. The ban was lifted in 2006, but still a void of industry investment remains.)

According to Michael Good, a vaccine researcher at Griffith University, no one is interested, commercially, in making a vaccine to prevent rheumatic heart disease because it mostly affects lower-income countries, which are not the most profitable markets. Pharmaceutical companies may be interested in a vaccine for tonsillitis or strep throat that could be sold in wealthy countries too, Good says, “but that’s not the main reason we’re in this game”.

Penicillin and other antibiotics remain effective against strep A, although some strains are developing resistance. Since the 1990s, Good has been trying to develop a vaccine to protect against strep A infections – and thereby rheumatic heart disease – by scratching together grants and philanthropic funding to sustain his group’s research. Roughly AU\$20m and three decades later, they have a vaccine candidate in a phase I safety trial of 45 volunteers.

It’s at this point that university-led research so often stalls – and why ASAVI could be critical. “When you step out of discovery research and move into development, it’s a different kettle of fish,” says Fulurija, who spent 15 years working in the pharmaceutical sector. “What ASAVI can do is bridge those two.”

DNDi has been active in South Asia since 2004, seeking ways to improve outcomes for the region’s people infected with neglected diseases. In India (above) and Bangladesh, DNDi has mainly focused on visceral leishmaniasis: the most serious of the three main forms of leishmaniasis because it’s almost always fatal without treatment. Visceral leishmaniasis affects internal organs including the spleen, liver and bone marrow, and is caused by protozoan parasites, which are transmitted by infected female sandflies.

Another world is on its way

Organisations like DNDi and the Mario Negri Institute demonstrate that it is possible and beneficial for drug research and development to prioritise public health over profit. But these initiatives and other alternate programs didn’t spring from thin air – changing an industry takes concerted effort on many levels.

“There needs to be pressure from below, from the public, from clinicians and from researchers – and there needs to be political courage from above to make changes,” Lexchin says.

And sometimes, this pressure gets real results. In late September 2023, two months after Johnson & Johnson announced its historic deal, the company dropped its patents for bedaquiline. The company will no longer enforce its secondary patents for the tuberculosis drug in 134 low- and middle-income countries, which represent 99% of global tuberculosis cases. Manufacturers can now make and supply generic versions of bedaquiline years before the secondary patents expire in 2027.

Five years ago, the drug cost in-need countries US\$67 per patient per month.

Competition between generic manufacturers is expected to bring prices down to US\$8. 🌱

CLARE WATSON is based in Wollongong, NSW. Her last story, on dengue fever, appeared in Issue 99.



Yirlinkirrkirr baleh?

Bininj Kunwok: “Grasswren where?”

The reappearance of a small, elusive bird that flits between clumps of spinifex grass and rocky outcrops in Australia’s Top End has ignited the imaginations of Western ecologists and First Nations people alike. Story and photographs by **David Hancock**.

Ecologist Cara Penton and photographer Kelly Dixon had trekked through tough, stone-country terrain in western Arnhem Land to a clearing among the spinifex. There, they put down a small, portable speaker connected by Bluetooth to Penton’s mobile phone.

As they retreated to the shadows, the speaker emitted a confluence of chirps and tweets.

“We really didn’t expect to see anything,” Penton says of the day, in 2022. “Then two birds scuttled out from the rocks. They were so curious and colourful, hopping about inspecting the speaker; it didn’t take long before they realised they had been tricked and hopped back to the security of the rocks.”

It was a seminal moment for the scientist and the photographer: their first sighting of the bird Bininj Aboriginal people know as yirlinkirrkirr.

ABOVE: PETER COOKE

“That was the ... only time I have seen yirlinkirrkirr in several years of working with Bininj people and wildlife on the Arnhem Land plateau,” Penton says. “I really look forward to the next time; it is such a beautiful and charismatic creature.”

Robust and long-tailed, and bedecked in bold chestnut, black and white feathers, yirlinkirrkirr (pronounced “yirl-in-git-git” in Bininj Kunwok language of western Arnhem Land) is an ornithological needle in a geographical haystack.

Also known as the white-throated grasswren, yirlinkirrkirr (*Amytornis woodwardia*) was thought to be on the verge of extinction at the dawn of the 21st century. During the 1990s there were sightings of the bird along the Arnhem Land escarpment between Katherine, about 330 kilometres south-east of Darwin, and Maningrida, 370km east of Darwin, but numbers declined as wildfires and feral animals (mainly cats) increased in the region.

The Arnhem Land plateau or “Stone Country” – known to Bininj as Kuwarddewardde – borders Kakadu and Nitmiluk national parks. It’s an ancient and forbidding landscape of layered sandstone cut deeply by gorges and crevasses. Bininj people have lived here for more than 35,000 years, taking advantage of the waterholes and springs, seasonal creeks and rivers, and abundant plants and animals. Records of their lives and those of the plants and animals that share this country adorn the walls and ceilings of thousands of rock shelters.

Since 2009, when Indigenous Protected Areas (IPAs) were first declared in and around Arnhem Land, Indigenous landholders have resumed

Ecologist Cara Penton (below, at left) and ranger Frankie Nadjimerick, right, set camera traps on the Arnhem Land plateau; Bininj traditional owner Terah Guymala (above) is always seeking mayh, small elusive creatures that make up much of the region’s native fauna.



management of much of yirlinkirrkirr’s home range. Changed burning practices and the determination of Bininj to rediscover and protect many threatened species has assisted the bird’s gradual return.

Other culturally important and endangered creatures in the region include the black wallaroo (*Macropus bernardus*), black-footed tree-rat (*Mesembriomys gouldii*), Arnhem Land rock-rat (*Zyomys maini*), fawn antechinus (*Antechinus bellus*), northern brushtail possum (*Trichosurus arnhemensis*), northern quoll (*Dasyurus hallucatus*), nabarlek (*Petrogale concinna*), short-eared rock wallaby (*Petrogale brachyotis*) and pale field-rat (*Rattus tunneyi*).

The relative stability of Kuwarddewardde afforded plants and animals protection from fire and flood over the millennia and allowed them to evolve in relative isolation. Many species, including yirlinkirrkirr, are found nowhere else on Earth.

In the past, while there was interaction with people on nearby lowland areas (often at periods of great abundance, such as magpie goose season), some clan groups rarely left the plateau, moving between waterholes and places of shelter and ceremony, exploiting niche food sources and trade networks. They burned as they travelled, establishing a land management system based on cycles of renewal and regeneration.

The plateau’s harsh terrain ensured Bininj were among the last Indigenous peoples to be affected by European society, and their links to traditional lands remain unbroken today.

But colonisation had an immense impact on the First Nations people of Australia’s north.

Many Bininj left their traditional lands, often in family groups, to work in buffalo shooting camps, missions and mines. They returned home infrequently or settled at church missions. Diseases introduced by Europeans, such as influenza and smallpox, took a terrible toll. By the end of World War II, only a handful of clans resided permanently on the plateau, and widespread traditional land management practices had declined.

Without the Bininj's constant care – and with the infiltration of feral animals such as buffalo, horses, cattle and cats – western Arnhem Land changed considerably. Fuel built up and uncontrolled fires, rare in traditional times, raged; many blazes were left to burn themselves out or be doused by wet season rains.

Bininj began to return to the plateau in the 1970s as part of a homelands movement, led by those wishing to resume their traditional lifestyle and take responsibility for management of familial estates. Small outstations linked by dirt roads and sandy tracks are now sprinkled throughout Kuwarddewardde and other parts of Arnhem Land.

Indigenous Protected Areas have become a way for the Australian Government to grow the National Reserve System and support traditional landowners; there are more than 80 IPAs scattered across Australia encompassing more than 85 million hectares – an area about twice the size of Switzerland. The Warddeken IPA (just under 1.4 million ha) covers much of the Arnhem Land stone country and is managed through a network of Indigenous ranger groups employed by Warddeken Land Management (WLM).

It has taken Bininj more than 10 years to bring the overgrown landscape under control through a program of prescribed burning that mimics traditional methods. Working with

Traditionally, Bininj collect strips of bark (below) to use as torches when setting fires. Working together (above), Bininj and balanda consult satellite maps to plot burning regimes.



Western scientists and using helicopters, vehicles and incendiary devices, they have developed a fire abatement scheme that has become the model for government-approved savannah burning that generates income from carbon credits. It's this income, along with philanthropic contributions, that substantially funds their land management and cultural programs.

Eyes on country

Constant wildfires are largely a thing of the past in western Arnhem Land, and Bininj are now focused on how to bring back native species, particularly small mammals (known as mayh) and birds whose habitats were scorched in previous times.

"There was a period where we went crazy throwing matches – in a good way – because everyone was so excited to be back on country," says Terah Guymala, a senior landholder and board member of WLM. "But we know not all country needs to be burned. We need to think about who is in this country as well. Our animals – kangaroos, reptiles, all species – need grass to hide or make nest, to breed and all that. They need it."

"No one looked after this country for a long time and all the animals started disappearing when the wildfire went through, chasing them and killing them. By the time we came back, their numbers were getting really small. That's what all the old people noticed – they said it wasn't like that back when they were here."

In 2016, Bininj embarked on an ambitious program to complement their renewed burning regime. WLM employed scientists to manage a



long-term camera study to discover which animals remained in Kuwarddewardde and where they lived. Since 2016, rangers have travelled to remote parts of the IPA to set out cameras and monitor wildlife. It is one of the largest privately funded wildlife monitoring programs in Australia.

According to Penton, WLM's ecology manager, the program was designed to last at least 10 years. Hopefully it will go on for decades.

"Monitoring isn't sexy," she says. "There is a lot of government funding for specific threatened species projects, which might be for 18 months or so, but the commitment to long-term monitoring is incredibly difficult. This project has been sustained by Bininj themselves, through reinvestment of savannah carbon credits.

"The environment works on long ecological timeframes – you can't see changes in a couple of years, even [in] this project where you are only looking at presence or absence. I think, as humans, we don't like waiting.

"To invest in something for such a period of time without seeing results is difficult to do, but there really is no other way. That's what monitoring is – looking after something and evaluating it over a significant period of time."

Each year, teams of rangers travel to 120 sites in 20 clan estates to strap cameras with motion sensors to trees or star pickets. The cameras are left out for five-week periods.

Penton and WLM ecology officer Erica Smith consult extensively with traditional owners before work begins and, over the course of a year, more than 50 rangers are involved in field work

"We are trying to evolve and do this in a meaningful way together – sometimes that is more Bininj way, sometimes more balanda [European] way."

WLM ecologist Erica Smith (above) uses a small speaker to conduct call-back surveys as rangers walk through country likely to contain yirlinkirrkir, and other hard-to-find birds – an opportunistic way to encounter the creature that sometimes produces results.

and image processing at three IPA ranger bases. Images of species are identified by Indigenous experts and scientists, labelled and placed in a bilingual database.

Information in the form of bilingual maps is given back to clan groups so traditional owners know what animals are recorded on their country. The data is important for planning future land management programs, particularly burning.

"When we did fire consultation this year, we put some of those species on our fire map, so when having discussions about fire we could protect certain habitats," Penton says.

"It is really important that information comes back to landowners. For a project to have such strong support after seven years, it is making sure the information goes back to the right people. As well, it informs rangers about their work and looks at that big-picture scale. Those results go through to the board of directors who develop a plan of management to ensure we are achieving the strategies we set out to do."

The camera monitoring has been successful for some species but not others. Sadly, no northern quolls have been recorded to date – but it



doesn't mean they're absent from the IPA, despite a dramatic downturn of the species in nearby Kakadu and other parts of northern Australia, including the Kimberley.

"We found the black wallaroo has a positive association with long unburned habitat," Penton says. "This could reflect their ecological requirement, or show the interaction between fire, feral herbivores and feral cats. For example, we know feral cats will hunt in fire scars for a long time after a fire passes through an area.

"If an area experiences a lot more fire frequency ... cats find it easier to move through; the same with buffalo – it reduces the complexity of vegetation by removing shrubs, by removing grass. New grass comes up after fire and animals are going to suppress the new grass by feeding.

"In the Top End, this landscape has been managed with fire for tens of thousands of years, so these species have evolved with fire, but now with the introduction of feral species and [a period of] removal of Bininj from country – and removal of their fire management – then with bringing fire management back, the interaction with the environment has been completely changed.

"That really is the crux of monitoring and why it's important. How we change our fire management going forward."

"This is where our stories are, where the oldest thing is connected to you. It is all written down here. This is our home and we still call it our home."

Erica Smith (above, in hat) and a group of daluk (female) rangers establish a song meter in an extremely remote location in the stone country. The women often walk for hours into terrain that can't be reached by vehicle or helicopter. They return several weeks later to retrieve recordings which are then electronically sorted.

Call and response

An unexpected result of the monitoring program was finding more yirlinkirrkirr, which prefer long unburnt areas of grassland.

The bird is significant to Western science because it's vulnerable; to Bininj people it's a part of culture – it's in their songlines and stories from old people. Some were discovered in places where Bininj songlines say yirlinkirrkirr would be found, rather than places that modern habitat modelling pointed to.

The bird, which generally lives in pairs or small family groups, is a poor aviator. It typically hops about and might undertake short flights from one area of cover to the next, so it can't easily escape fire.

"Everyone is pumped for this bird," says Smith. "Yirlinkirrkirr has really brought a lot of excitement to the communities, to the rangers, to us and people who visit the IPA.

"I think a lot of the excitement came from the consulting process from the very start. The traditional owners got to fly around in helicopters and point out where they had seen them in the past, or where the songlines suggested the bird might be.

"When we actually found the bird, it was a really joyous time for people. People are happy, people want to protect it and people want to get out on country and try to find more. It's been a great tool to teach the importance of having different fire regimes on country."

The search for yirlinkirrkirr has expanded into other methodology – rangers conduct call-back surveys when they walk through country by stopping regularly to play the bird's distinctive call, a mixture of complex trills and chirps, with an alarm call characterised as a sharp "tzzzt". Solar-powered song meters are strategically placed across the plateau, and rangers use AI algorithms to extract the song of yirlinkirrkirr.

"We found birds down around Jawoyn country, in the south, and they are in some places in Kakadu but we believe the best potential habitat is here, across the stone country," Smith says. "We just need to track down exactly where they are."

The monitoring program has also detected cats in all parts of the IPA.

"Cats are really difficult to deal with on such a large scale," Penton says. "The best way may not necessarily be by reducing the number of cats but reducing the impact they can have.

"If an area has more complex vegetation their hunting efficacy goes down ... If you can manage your fire and suppress or manage feral herbivore populations you can have more complex vegetation and landscapes."

Two worlds

Penton and Guymala agree the monitoring program has benefits far beyond locating and preserving endangered species.

"The co-benefits are getting people out on country, accessing ancestral homelands, building up the professional development of Indigenous rangers in collecting data, creating data and storing data where, in this new age, data is gold," Penton says.

"It's not just putting out cameras together; we are going through the process of this analysis together. We are trying to evolve and do this in a meaningful way together – sometimes that is more Bininj way, sometimes more balanda [European] way. That process weaves in and out and around each other."


Guymala says western Arnhem Land is being revived by Bininj people who have re-established



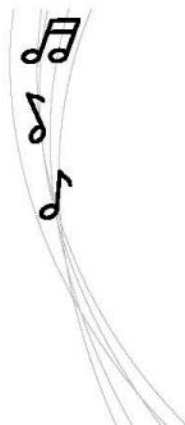
Dean Yibarbuk (top), chairman of WLM, is determined that knowledge is passed on to Bininj youth (above), who are encouraged to go out on country with scientists and traditional owners alike.

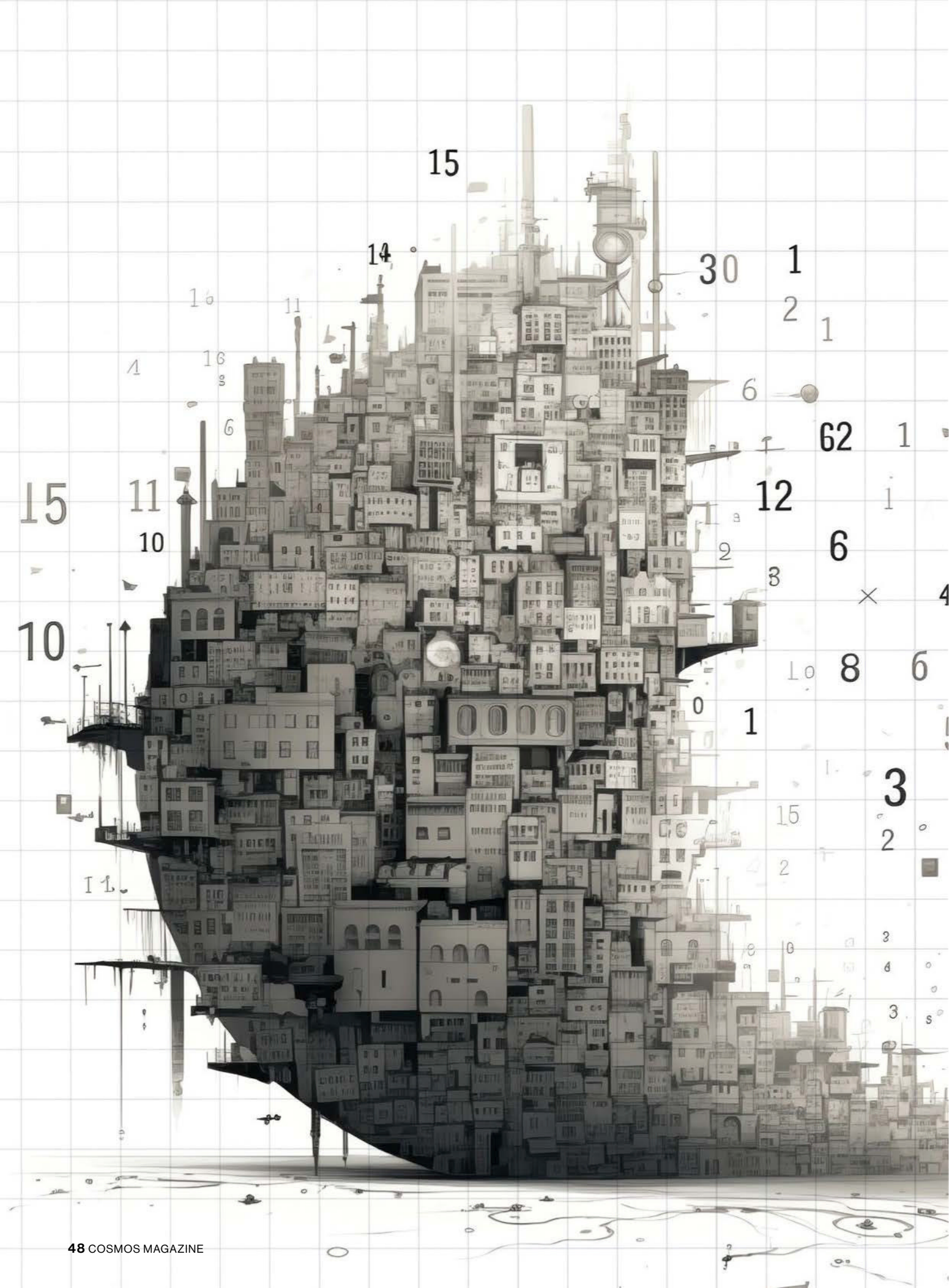
ancestral contacts with the land and creatures like yirlinkirrkirr.

"This is where our stories are, where the oldest thing is connected to you," he says. "It is all written down here. This is our home and we still call it our home. We want our kids to learn, to manage and to live in this country properly and also bring this Western education and Bininj education together – because we want them to survive in two worlds.

"They are singing about the animals and the fire, so they are picking up culture. They can only do this here and it is very important because we want our kids to continue living like this. When we go, we want them to be really strong and standing on their own feet." 

DAVID HANCOCK is based in Darwin. His story, about restoring rock art in Stone Country, was Issue 99's cover.





BORN TO RULER?

Think you're "just bad at maths" and can get by without it? And what do mathematicians actually spend their time doing?

Petra Stock talks to number professionals about their work, and why they're not as odd as some might think.

Long-running television show *8 Out of 10 Cats Does Countdown* is an edgy spoof of a letters and numbers quiz.

Hosted by comedian Jimmy Carr, a rotating panel of comics compete, with maths providing the axis for numerous jokes and jibes.

In one episode, resident maths whiz Rachel Riley neatly solves a puzzle, organising a set of six numbers and operators (+, -, x and ÷) to make them equal 576. One of the comedians responds – to laughter and applause from the audience – “What happened to you? How did you become like this? How many friends have you got?”

According to mathematician-musician Alexander Hanysz, the show reflects wider attitudes and public perceptions about maths. The contestants are consistently “quite good at the words, they’re proud of it and they’re creative,” he says. “And then you get to the numbers, and people revel in being bad at it. I wish we could change this about the world.”

“I’m just bad at maths” has become the popular refrain, a self-fulfilling prophecy that people are naturally pre-disposed to words or

numbers, but never both. Perhaps it’s no surprise, then, that the public increasingly doesn’t want to do the maths, a fact borne out by statistics showing declining maths participation and performance in Australian children.

Unlike literacy skills, which are widely considered essential, the numeracy realm is regularly dismissed as an inborn ability (the idea of a ‘maths brain’ hardwired from birth): something that’s abstract, solitary and square, with limited career opportunities outside banking and teaching.

In fact, maths graduates are highly employable in a wide range of jobs, and their backgrounds and childhood skills are just as diverse. Is a lot of what we think about the field and its participants based on faulty calculations?

MATHS: INNATE OR LEARNT

Today Hanysz is employed at that maths-positive workplace the Australian Bureau of Statistics, the agency that casts its role as telling “the real story of Australia, its economy and its people by bringing life and meaning to numbers”.

After a first PhD attempt in his twenties “crashed and burned”, Hanyasz spent more than a decade working as a full-time classical pianist, before returning to university for a second go.

From the abstract land of a pure maths PhD, Hanyasz eventually found work in the practical world of the ABS. His day job involves sourcing independent, reliable data for telling Australia’s story through numbers. An example is an experimental indicator of household spending, drawing on aggregated and de-identified bank transaction data.

It might sound dry, but when Hanyasz talks about maths, he leans in to the lyrical. “It’s simultaneously an art, a science, a game and philosophy,” bundled together with 3000 years of history, he explains. Nonetheless, in most social situations, Hanyasz avoids talking about the subject he loves. It makes people uncomfortable, he says, so he talks about music instead.

“I find if you talk about maths, people are scared of it. You get the stories about how people were so bad at maths at high school. Or they think if you’re good at maths, you’re some kind of freak.”

Hanyasz describes his pathway into maths as a “succession of lucky accidents”. And contrary to the popular misconception that maths ability is innate, many mathematicians recall challenges along the way.

Professor of mathematics at the University of Tasmania, Barbara Holland, always liked maths, and grew up with the benefit of “two geeky parents who were both high school teachers”, but she says things weren’t always smooth sailing.

When she was 14, Holland remembers getting viral pneumonia and missing a month of



Alexander Hanyasz,
data analyst,
Australian Bureau of
Statistics



Barbara Holland,
mathematical biologist,
University of Tasmania

school. She returned to class just in time to face an end-of-unit test in trigonometry.

“And I’m like: what’s trigonometry?” she says. “Why is everyone chanting ‘SohCahToa’ like they’ve joined some weird cult or something?”

Holland did miserably in the assessment, and found herself completely floundering. But thanks to the support of another teacher who was willing to help struggling students, she caught up.

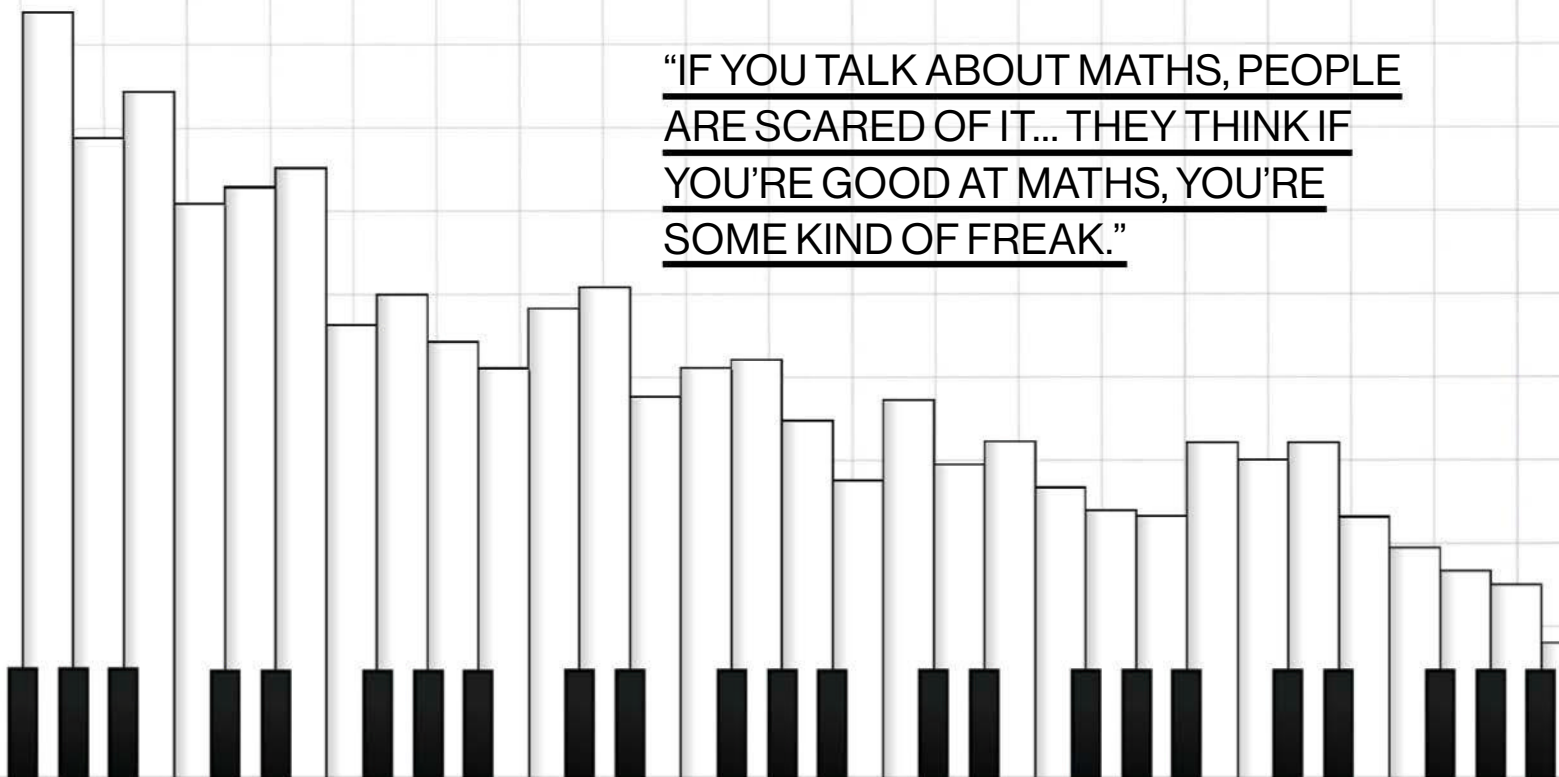
Two lessons from that formative experience have stayed with her. The first is the way in which one good teacher can make a difference in someone’s life. The second, that there need to be easier ways for students to catch up.

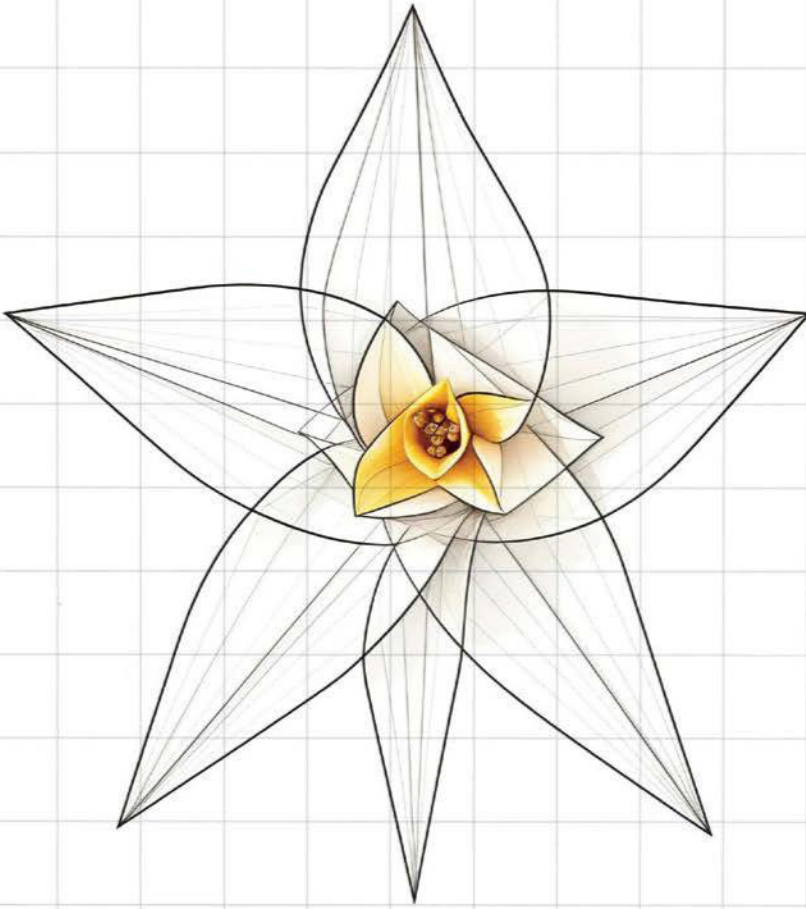
“Maths is so linear when you learn it in school,” Holland says. “If you miss some essential building block then it makes everything else quite difficult.”

It’s a sentiment shared by Dr Alexandra Hogan, a mathematical epidemiologist at the University of New South Wales. Hogan has spent the last few years writing equations to model the spread of COVID-19: what proportion of the population is susceptible, infectious or recovered, and how limited vaccine supplies might be fairly rolled out for maximum public health benefit. During the pandemic, she worked as part of a large team using science and maths to inform policy, including providing evidence to bodies like the World Health Organization to use in their vaccine planning.

She says that like many people, she found maths at school “really hard”. But she ultimately persevered thanks to the help of supportive

“IF YOU TALK ABOUT MATHS, PEOPLE
ARE SCARED OF IT... THEY THINK IF
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SOME KIND OF FREAK.”





teachers and university lecturers. “It wasn’t an easy thing to do. It was really difficult. But I stuck at it, because I still enjoyed it. And I realised that it’s okay to find things hard and you don’t have to succeed every time.”

Luckily, persevering with maths pays off, sometimes in unexpected ways.

MORE THAN NUMBERS

Surveys of parents, educators and career advisors by the Australian government’s Youth in STEM (science, technology, engineering, mathematics) study suggest limited awareness of the potential career paths available from studying subjects like maths or science.

When 730 teachers and career advisors were invited to list as many STEM-related careers they could think of, the top response was teacher or educator (14%). When parents were asked a similar question, the highest response was engineer (11%).

Growing up in South Africa, with a father who was a Hungarian refugee, Dr Éva Plagányi saw maths as a universal language. She always enjoyed maths at school, yet couldn’t picture it as a career. “I had this idea that mathematicians would end up sitting in a little room working on problems all day. I didn’t want that, because I was quite an outdoors person,” she says.



Alexandra Hogan,
mathematical
epidemiologist,
University of New
South Wales



Éva Plagányi,
senior principal research
scientist, CSIRO

Engineers Australia estimates Australia requires an additional 50,000 to 100,000 engineers by 2030 to meet the needs of the clean energy transition, major infrastructure projects, space, and emerging areas like artificial intelligence, robots and the AUKUS defence pact between Australia, the UK and US.

She remembers one teacher saying, “you’re going to have a job in mathematics one day ... you’re going to be a bank teller.”

When she took this information home, Plagányi’s father told her instead of counting money, perhaps she could be a scientist. At university Plagányi studied zoology, botany and applied mathematics, even though “I had no idea what I would actually do with the mathematics”.

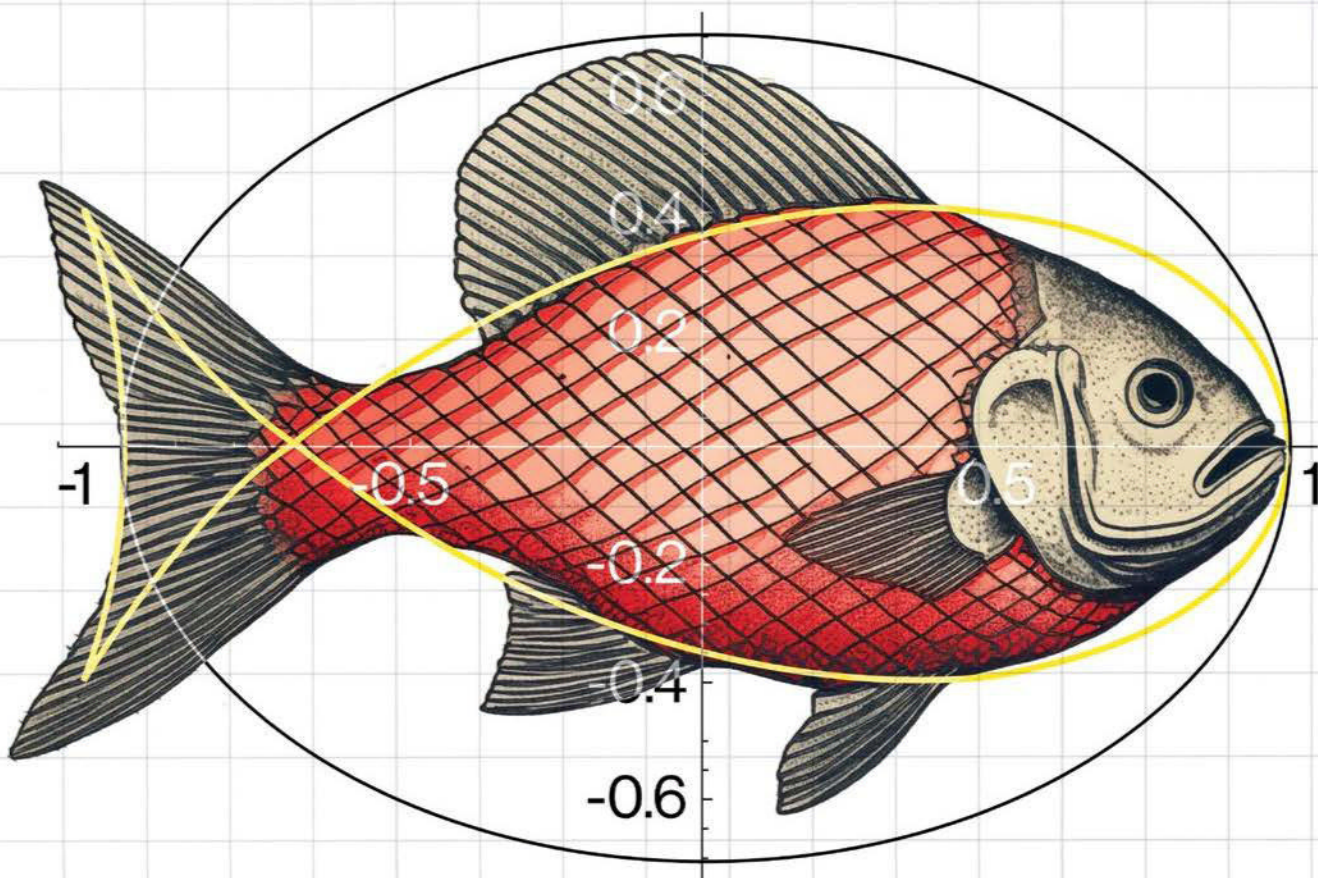
She remembers seeing books in the library about how the Fibonacci series can describe the petals of flowers. “I thought: Well, that’s great, but it’s not very exciting.”

In her second year, a lecturer spoke about using maths to model antelope populations to assist with conservation efforts. Plagányi says: “I still remember rushing to his office and saying ... ‘That’s what I want to do!’”

Today, she works with the CSIRO using maths and biology to solve complex, real-world problems about resource use and conservation. Much of her day job involves managing fisheries, combining data collected from the field with equations describing how fish populations change in the ocean. There’s no single right answer, but her models can be used to test options and guide decisions on management strategies like fishing quotas, which try to balance the needs of people and the environment.

“For example, if you’re harvesting krill, you want to leave enough to ensure that whale populations are healthy,” she says.

A large part of Plagányi’s role involves communicating with others, explaining the models to policymakers, and stakeholders like Traditional Owners or fishers who are directly impacted by the results of her work. She emphasises that’s why it’s so important to ensure the



models are meaningful, and to have confidence in their results.

“If you get the numbers wrong, you could close a fishery. That’s people’s livelihood,” she says.

Plagányi’s job weaves together her loves of maths, nature and the ocean, and she gets to travel, work with people and spend plenty of time outdoors. But for a long time, she couldn’t see anybody using maths in that way: unlike doctor, lawyer or the ever-popular marine biologist, few can picture a career in maths beyond the limited options of bank teller or maths teacher.

When Kate Simms was at school, plenty of older people warned her against pursuing



Kate Simms,
lead researcher,
The Daffodil Centre

further study in maths, even though it was her favourite subject.

Happily, for Simms, she ignored their advice. She now works on modelling the impact of cervical cancer prevention strategies like vaccination and screening at The Daffodil Centre, a joint venture between the University of Sydney and the Cancer Council – and she still loves the adrenaline rush of solving an interesting problem.

Simms says her university maths cohort have all ended up in diverse careers – everything from cryptography to modelling internet speeds, from public service to finance.

“The skill set and the way of thinking is so flexible, useful in so many different ways ... Even though there’s not necessarily a defined job, maybe one of the reasons for that is because there’s so many jobs,” she says.

Professor Tim Marchant from the University of Melbourne agrees. The director of the Australian Mathematical Sciences Institute says students – and especially their parents and career advisers – need to know that even though there might not be many jobs labelled ‘mathematician’, the market for maths graduates is

“A WORLD WITHOUT MATHS? THERE’D BE NO TIME, NO BAKING, NO PAGE NUMBERS IN BOOKS, NO SPORTS SCORES, NO TRAVEL OR NAVIGATION.”

absolutely booming, with the starting salary for many roles at around \$100,000 a year.

“Jobs involving data science, financial mathematics – there’s not enough maths graduates to fill those jobs,” he says.

Marchant lists sectors where strong quantitative skills are in high demand: big technology companies, economics and finance, medical fields, engineering. So much of the modern world is now governed by data that numeracy skills are in high demand.

And it’s not only quantitative skills employers are after. Recently Holland noticed that many of her maths PhD students were ending up in government and social services jobs.

“I was rung up a few times to give a reference,” she says. After a sequence of successful candidates, Holland couldn’t help but ask the person on the end of the line: “This isn’t necessarily the sort of job you’d think a maths graduate would get. What attracts you to maths PhD students in these sorts of roles?”

“Well, they’re so resilient to being stuck,” the recruiter replied.



Tim Marchant, Australian Mathematical Sciences Institute, University of Melbourne

The PISA (the Programme for International Student Assessment) survey tests 15-year-olds against essential literacy and numeracy skills. In 2003, only four countries out-performed Australia on the maths PISA. By 2018, Australia had dropped to 24th.

Holland reflects that’s probably because “a lot of the time in maths being stuck is the natural state”. “To try and creatively think your way out of a problem and see it from a different angle is often what helps you make progress.”

GAINS AND LOSSES

Mathematicians might be applying their craft to solving problems from evolution to economics, public health to environmental management. But what about the rest of us? Do we really need maths?

The ready acceptance of being “just bad at maths”, is underpinned by a pervasive view that we can get by in life without it.

But it’s not only the mathematicians, engineers or data analysts who need numeracy skills.

Video game designers and programmers use maths to present everything that appears on screens, from the tiniest pixel to vast virtual worlds.

Craft brewers measure water, hops and barley to achieve the perfect flavour profile, and use calculations to estimate heat and alcohol content.

Social media influencers analyse data to measure engagement and maximise reach.

Fashion designers and carpenters rely on geometry.

Name a task and it probably involves maths.

In fact, research suggests people with poor numeracy skills, particularly women, experience more disadvantages in life.

A large-scale longitudinal study in the UK by researchers Samantha Parsons and John Bynner followed a sample of people born in 1958 and 1970 – about 17,000 in each cohort – through to adult life.

By the time people entered their 30s, those with poor numeracy skills were more likely to experience depression and have difficulty finding and maintaining employment compared to those considered to have competent maths ability.

They also found a correlation between women with poor numeracy skills and substantial socioeconomic disadvantage – in terms of employment, physical health and a sense of control over their lives – regardless of their levels of literacy.

Parsons and Bynner conclude: “Poor numeracy skills make it difficult to function effectively in all areas of modern life, particularly for women.”

Maths is fundamental to our everyday existence. A world without maths? There’d be no time, no baking, no page numbers in books, no sports scores, no travel or navigation.

No understanding of atoms and density, no rockets, no bridges.

No symmetry. No poetry. No music.

Beyond the practical and pragmatic, maths can offer a measured perspective on the world.

Hogan says maths training helps you think about things in a quantitative way, assessing evidence and making objective decisions. “That’s an incredibly useful skill to have”.

Plagányi likes the way maths reduces complexity in the world. It’s a structured, consistent way of explaining everything in nature.

Hanzs asks: can you imagine a school system where people had never heard of Shakespeare? And no one was ever encouraged to go for a run, or jump in a swimming pool?

“It’s part of our culture,” he says. “The ability to do maths is part of what makes us human.”

PETRA STOCK is a journalist at *Cosmos*. Her last story, on robotic animals, appeared in Issue 100.

Starry, starry night

The Royal Observatory Greenwich's Astronomy Photographer of the Year competition isn't just about pretty pictures. Look closely: some of these images contain new knowledge of the universe.

Andromeda, unexpected

When amateur astronomers peered up at our closest spiral galaxy, Andromeda, in one of the most observed areas of the sky, they didn't expect a surprise. But 22 nights and 110 hours of data revealed a huge arc of plasma across their image. This curved cloud of ionised oxygen gas is an emission nebula dubbed the Strottner-Drechsler-Sainty Object 1, and it's set the imagination of the astronomy community ablaze.

Winner (Galaxies); Overall winner

Photographers: Marcel Drechsler, Xavier Strottner and Yann Sainty

Neighbours

Feet on the ground in the Bendleby Ranges, four hours north of Adelaide, photographer Paul Montague visited another galactic neighbourhood. These three worlds-of-worlds are (from left) IC 879, NGC 5078 and NGC 5101.

Highly commended (Galaxies)

Photographer: Paul Montague







Sky sprites

During thunderstorms we're mesmerised by lightning striking the Earth, but electrical discharges occur high above storms too. Lightning sprites – flashing through the mesosphere in a tenth of a second – are difficult to see and capture on film. Photographer Angel An recalls standing on a ridge in the Himalayas, watching the dancing sprites: "They acted as fairy-like creatures, giving a transient firework show for the audience on Earth."

Winner (Skyscapes)

Photographer: Angel An

Brushstroke

We're used to seeing images of an aurora firmly placed in the context of the Earth: the flickering, ever-changing light paused over mountains or trees or ice. But this photograph frames the aurora borealis in isolation. Abstracted from the familiar, what do you see? Electrons riding the solar wind and striking oxygen molecules? The stroke of a paintbrush across an inky background? The veil between worlds?

Or something else entirely?

Winner (Aurora)

Photographer: Monika Deviat



Circle of light

Skagsanden beach in Norway's Lofoten Islands is usually rolling with waves perfect for beginner surfers – in fact, the beach is home to a popular surf camp. But on this winter's night, the water stretched still enough over the sand to hold a reflection of the sky above, joining the curve of an aurora into an ellipse that encircles Hustinden mountain.

Runner-up (Aurora)

Photographer: Andreas Ettl



Close encounters of the Mars kind

Immersed in cloudy layers, the full Moon is accompanied by Mars (the yellowish speck below the Moon, at right). "The colourful hue that surrounds the Moon is a lunar corona formed while bright moonlight is diffracted by water droplets in thin clouds, drifting in front of the lunar disc," explains the photographer.

Highly commended (Our Moon)

Photographer: Miguel Claro

The heart of Hydra

In their quest to discover new nebulae, amateur astronomers Drechsler and Strottner not only captured the winning image of the 2023 competition (page 55) but also added to our understanding of binary star system evolution. By trawling through old star surveys, the pair found this binary star system surrounded by a large and previously unknown galactic nebula, 15.6 light-years across – then photographed it.

Winner (Stars and Nebulae)

Photographer: Marcel Drechsler

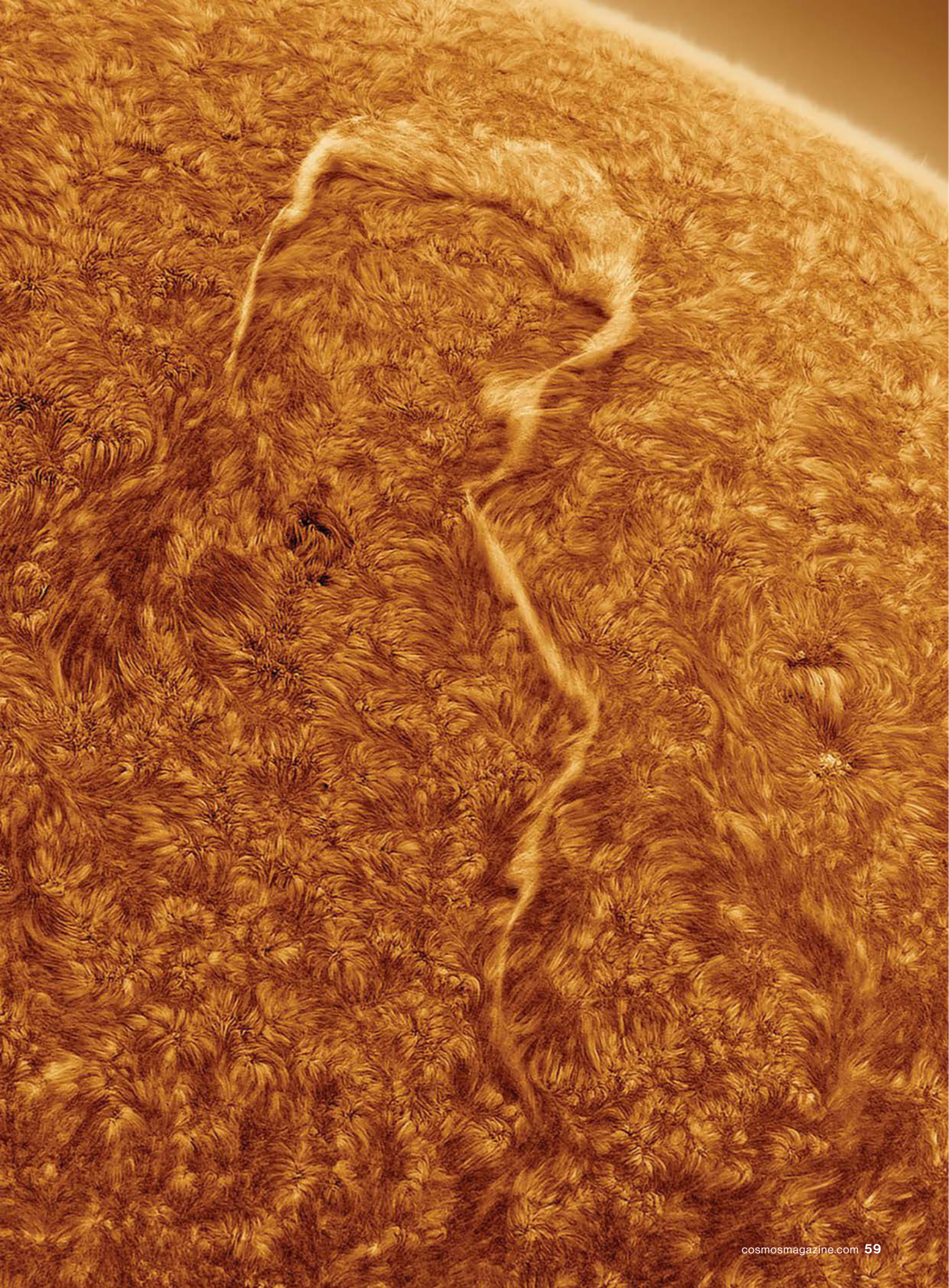
The solar question

Though it appears other-worldly, this is a real image of the Sun, with a filament curved into the shape of a question mark. Filaments are structures on our star's surface, made of plasma that is shaped and reshaped by magnetic fields. "[The Sun] wanted to show us in a very graphic way that it is a star with many unanswered questions," the photographer muses.

Winner (Our Sun)

Photographer: Eduardo Schabberger Poupeau





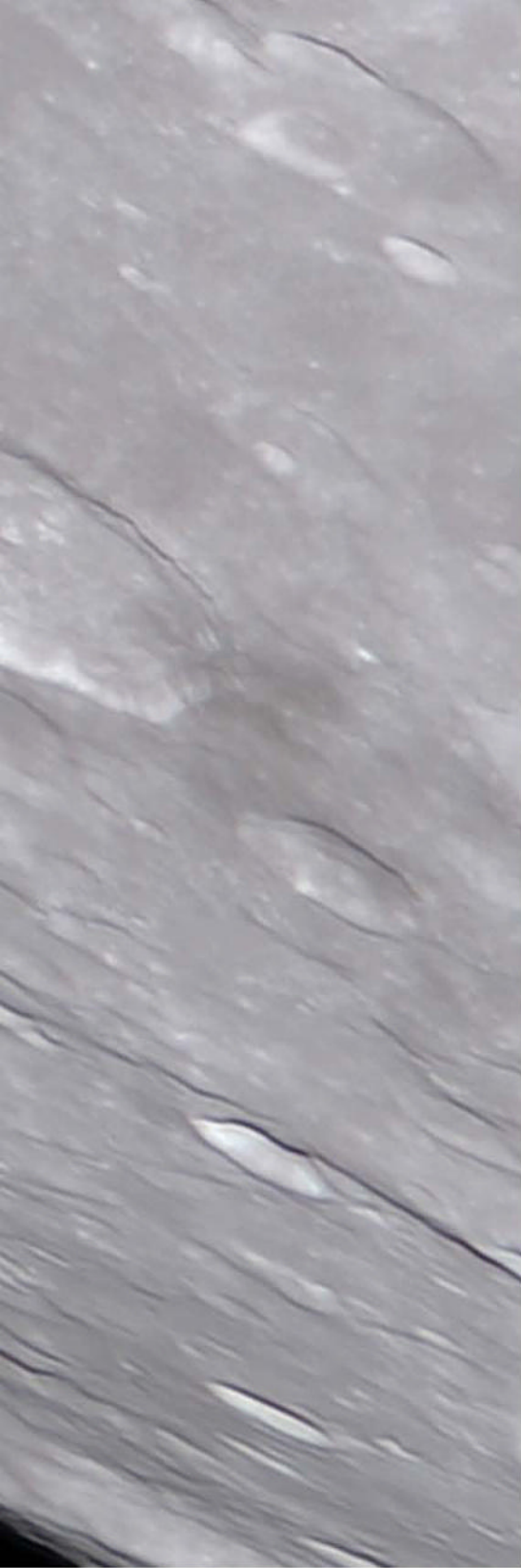


▲
Mars-set

Though this Earthrise-esque image looks like it was snapped by an astronaut orbiting above the lunar surface, it was in fact taken from Earth during an occultation of Mars. The Moon and the Red Planet were both at opposition (directly opposite the Sun relative to Earth) when the Moon passed in front of Mars, allowing the photographer to line up this incredibly tangible shot.

Winner (Our Moon)

Photographer: Ethan Chappel



Two bridges

14-year-old Haohan Sun captured the progression of moonrise over the Xinghai Bay Bridge in Dalian, China, a major port city on the Yellow Sea. The colour change from molten red to pale gold is caused by atmospheric extinction. Nearer the horizon, the Moon's light passes through more of our atmosphere, which scatters away the bluer wavelengths of light. The effect can be magnified by dust or pollution.

Highly commended (Young)

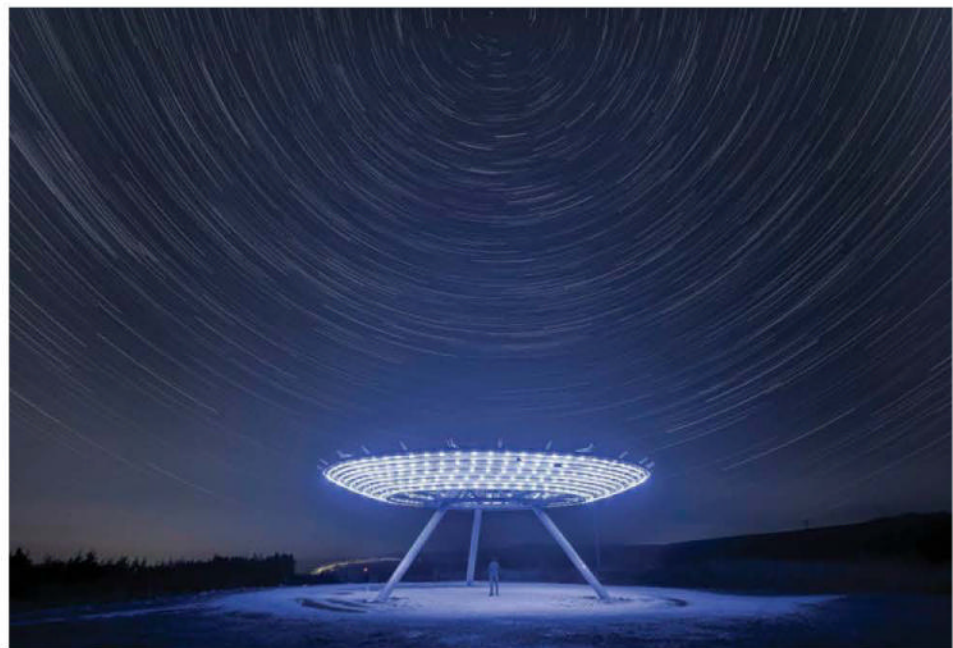
Photographer: Haohan Sun

Spielberg who?

Nestled in the hills of Lancashire in the UK, this 18-metre-diameter sculpture lights up nightly with 500 low-energy LEDs, powered by a nearby wind turbine. Called Haslingden's Halo, it appears like a UFO hovering between the town below and the trails of stars above. The Halo is one of four large-scale sculptures built in the area, collectively called panopticons: structures providing a comprehensive view. But of the Earth, or of the universe?

Highly commended (People and Space)

Photographer: Katie McGuinness



What's known about the science of fire? What data do we have, and how has it changed our approach to fire over the last decade? **Bianca Nogrady** reports on the researchers learning about the phenomenon we both fear and need.

Burning questions



To a firefighter, whose fragile skin is protected only by a centimetre or two of heat-resistant fabric, a bushfire is a roaring, leaping beast of flame and fury. It is both unstoppable and unpredictable in its onslaught, a creature of pure physics. But to a firefighter facing that maelstrom in the fullness of its power, a bushfire takes on a living quality, like a dragon rampaging across a landscape, crushing all life and structures in its path.

To a home, built defiantly on land that has been cyclically scoured by fire long before even the Indigenous ancestors set foot on this continent, a bushfire is heat, flame, wind and embers. Atmospheric temperatures can reach 1,600°C, hot enough to melt concrete, glass and steel. The flames themselves are a mere 600°C at their tips, but still carry enough thermal clout to crack a glass window. That heat drives – and is driven by – wind. If the conditions are right, those winds can approach speeds normally associated with major tornadoes. But they pack an extra punch: tiny, red-hot embers that can slip through even the smallest, sub-millimetre-sized gaps to ignite the soft underbelly of a house.

To a nation that has expanded rapidly over the past few centuries in the thin strip of habitable territory between desert and ocean – a strip once lush with forest, grassland and scrub but now sprouting communities, power and telephone networks, homes and offices, roads and highways – a bushfire is a flaming spear hurled into the complex engine of modern civilisation. It disrupts everything with smoke, chaos, panic and tragic, expensive loss. It is a thing to be feared, and increasingly so with the climate change brought on by the combustion of fossil fuels.

But to a gnarled and warty old man banksia, its boughs heavy with woody seed pods, a bushfire is the necessary catalyst for reproduction. Heat and flame trigger the pursed-lipped seed pods to open and spit out their precious cargo. Those seeds land in a soft bed of nutrient-rich ash cleared of competitors, equipped with everything they need to grow and flourish.

For tens of thousands of years, humans and ecosystems on this unique continent have learnt to live with bushfire as a healthy and necessary feature of the landscape. But colonisation, and now climate change, have profoundly altered that relationship in ways that Australia is only just starting to come to grips with. As the planet

warms and patterns of rainfall shift, the timing, frequency, distribution and intensity of bushfires are shifting too. Everyone from fire ecologists and pyrogeographers to town planners and engineers are working to understand how this changing relationship will impact all forms of life on this continent, and how we can prepare and adapt for it.

These responses have to be informed by data. To adapt, we need to understand how, when, where and why bushfires occur, property and infrastructure are affected, people are injured or killed, and ecosystems are damaged. The constantly shifting landscape of climate change – rising temperatures, worsening droughts and longer, more intense bushfire seasons – has added a new urgency to the scientific quest to help Australia renegotiate its relationship with fire.

FIRE

A flame has simple needs. Give it energy (heat), fuel and oxygen – the so-called “fire triangle” – and it will live. Remove any one of those three elements, and it will die.

But that trifecta alone isn’t enough to explain how and why a single flame swells into a deadly fire storm. Instead, fire scientists look to the ‘fire behaviour triangle’: topography (the lay of the land), weather and fuel. These factors decide whether a single flame becomes a bushfire, how big that fire becomes, where it moves and how fast it travels.

“When you think about the bushfire, its main feature is that it’s a free-spreading fire on the landscape,” says Miguel Gomes Da Cruz, a bushfire behaviour scientist at CSIRO. “What has been always my aim is about how can we better predict this movement, how the fire responds to wind, availability of fuels and so on.”



To understand the effects of fire on our ecosystems, scientists look to nature – like the regenerating banksia (above) – but also simulate fire with a range of burning conditions and fuels, like in CSIRO’s Pyrotron (below).



Topography is perhaps the easiest of the three factors to work with, because it’s easy to map and it doesn’t change unpredictably. Fire travels faster uphill, and the steeper the slope, the faster it moves. A general rule is that for every additional 10 degrees of slope, fire moves twice as fast.

Weather is more complicated, because it includes humidity, temperature, wind and rainfall. But those factors are at least measurable and to some degree forecastable, even as they change over time with climate change.

Fuel is where things get really tricky. It’s difficult to measure accurately, varies enormously even over short distances, and is constantly changing. But fire science is getting better at understanding fuel. In the 1960s, CSIRO fire scientist Alan McArthur developed the Forest Fire Danger Index, a measure of the potential impact of a bushfire on any given day, in any given place and conditions. That index underpins our current Australian Fire Danger Rating System, which is familiar to most as the colourful semi-circular warning signs dotted across the roadscape.

But this system has undergone a massive overhaul in the last decade, informed by half a century of fire behaviour research. One of the biggest

changes is to the variety of fuel types; while McArthur's original calculations only took two fuel scenarios into account – grassland or forest – the new system considers eight, including spinifex, mallee heath, pine and grassy woodland. This allows a much more accurate forecasting of the fire danger risk in any location based on the landscape – for example, the possibility of fast-moving or tree-crown fire. The updated fire danger ratings also factor in weather; how recently an area has burned; the chance a fire will impact infrastructure, properties and people; and how easy it might be to suppress a fire in that location.

Cruz says that it's a huge leap forward, but there's still a way to go. "One of the main limitations we have in knowledge is not about how the fire burns, but how the fuels are mapped," he says.

Even with the new rating system being more tailored to fuel types, the actual maps of what's on the ground across the country are still relatively crude and old. That will be improved by a Western Sydney University initiative to create a digital map of the entirety of Australia's vegetation down to a resolution of five kilometres squared. There's also research underway to understand how different vegetation landscapes and their fuel potential is changing with climate change.



Miguel Gomes Da Cruz,
bushfire behaviour
scientist,
CSIRO

All of this will be fodder for bushfire models. But as Cruz points out, "one thing with bushfires is that everybody sees them differently". In the United States, where Cruz completed his masters and PhD, bushfire modelling is driven more by an understanding of the physics of fire. "In North America when they started doing the modelling in the late sixties ... they had some mechanical engineers – people that look at wind flow, heat transfer, things like that – and that really guided through decades of research," Cruz says.

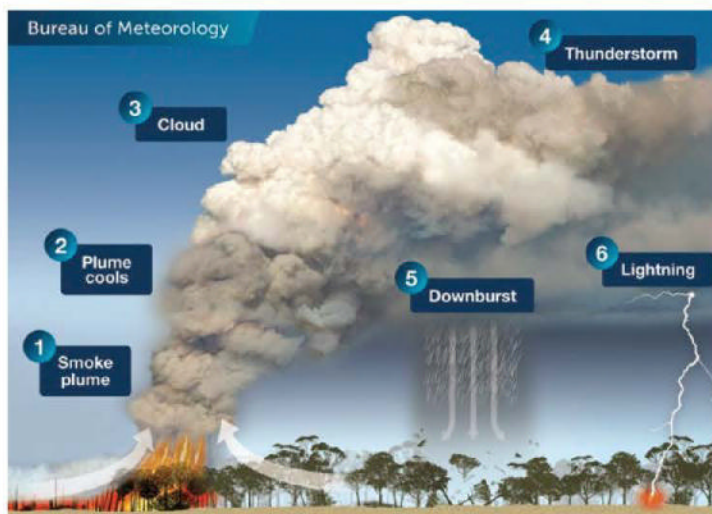
In contrast, in Australia, it's all about fuel. "In Australia and also in Canada, we have foresters doing the fire research," says Cruz. That means modelling starts from understanding the underlying fuel situation and how that influences fire behaviour.

Regardless of what perspective bushfire behaviour scientists are coming from, their



**CLIMATE CHANGE HAS ADDED
A NEW URGENCY TO THE
SCIENTIFIC QUEST TO HELP
AUSTRALIA RENEGOTIATE ITS
RELATIONSHIP WITH FIRE."**

Fire weather



Bushfires can generate intense phenomena such as pyrocumulonimbus clouds. As a plume of hot, turbulent air and smoke from a fire rises, it mixes with cooler air and spreads out. It continues to expand and cool as it rises and the atmospheric pressure lowers, until the moisture in the plume condenses and it forms a pyrocumulus cloud. If the conditions are right, this cloud can reach the cold upper troposphere. Cooling ice particles in the cloud build up electrical charge, causing a thunderstorm: a pyrocumulonimbus cloud, or flammagenitus.

models need observational data. That comes both from controlled experimental fires, and wild untrammelled ones.

CSIRO's National Bushfire Behaviour Research Laboratory, perched on the eucalypt-covered hillside of Canberra's Black Mountain, houses two unique laboratories to study fire behaviour in highly controlled conditions. The Pyrotron is a 29-metre-long wind tunnel where fire scientists burn carefully prepared and quantified fire fuels, such as leaves and grass, in front of a fan that can generate wind speeds up to 60 kilometres per hour. This allows them to study the effect of wind on the movement of fire and embers. Nearby, a 12-m-tall vertical wind tunnel enables the study of how burning embers behave when transported upwards by wind.

But these conditions are to a bushfire as a home freezer is to Antarctica. So the next step for bushfire experiments is out in the open.

Around 200km south-east of Adelaide, the mallee heath of Ngarkat Conservation Park is the largest area of remnant native vegetation in South Australia. It's also a site that has provided a wealth of data on how fire behaves in mallee heath and scrubland, through the controlled ignition of experimental plots across the landscape.

Each of these experimental plots – ranging in size from around 250–750 sq.m – are dotted with 1- or 2-sq.m sites, so researchers can measure the fuel load and structure in detail. That involves sorting, weighing, sizing and even assessing the moisture content for every bit of fuel in those sample patches. Air temperature, humidity and wind speed are also carefully recorded.

When a plot is set alight, fire behaviour observers in close proximity to the flame front – not a job for the faint-hearted – record at regular intervals characteristics like flame depth, height and angle, whether spot fires are igniting ahead of the fire front and whether the flame burns up into the crowns of trees.

These controlled bushfire experiments are constantly taking place around Australia, in different locations, different conditions and over different time periods. Lighting a fire on total fire ban days, even in a controlled setting, requires a fair bit of trust with local fire authorities – but as Cruz says, “if you want to get the data that matters, that’s when you need to burn”.

But controlled bushfires are still a far cry from the real thing, so bushfire behaviour modelling also needs data from the coalface. Every bushfire is now a source of data, whether from direct observations of firefighters on the ground, aerial footage in visual and infra-red, post-bushfire surveys of damage or even satellite data. It’s a challenge to collect data in an environment where temperatures can melt glass and steel, where embers can spark new fires



Justin Leonard,
Bushfire Adaptation
research leader,
CSIRO

kilometres ahead of a fire front, where thick plumes of smoke can obscure even infrared sensors, and where firefighting agencies’ need for unfettered access to the skies rules out the use of unmanned aircraft such as drones. But as technology advances, so does the ability to collect data from even the most dangerous fires.

This data then informs models that are becoming ever more sophisticated and accurate in their ability to take the pulse of the landscape, weather and fuel load, and predict when, where and how bushfire will strike. But climate change is moving these goal posts. Bushfire models are therefore



IT’S A CHALLENGE TO COLLECT DATA IN AN ENVIRONMENT WHERE TEMPERATURES CAN MELT GLASS AND STEEL.”

being designed with the flexibility needed to take into account that vegetation landscapes are altering, fuels are getting drier, rainfall is becoming less predictable, heat waves are becoming more extreme and wind patterns are shifting.

“To the degree that we understand climate change, we’ve got a reasonable handle on its implications for discrete fire behaviour at a point,” says CSIRO bushfire scientist Justin Leonard. But

ENGINEERING BUSHFIRE-RESILIENT HOMES

At the Queensland Fire and Emergency Services testing facility, a grey box the size of a bathroom is blasted with flame.

The box is a prototype of a bushfire-safe room, designed by researchers at the Queensland University of Technology. The outside of the box is clad with autoclaved aerated concrete – a lightweight concrete dotted with closed air pockets – over an insulated steel frame.

During the test, one wall is exposed to direct flame temperatures approaching 1000°C. But on the other side, the temperature remains a balmy 28°C.

Australia is among the best in the world for its rigorous, detailed and evidence-based bushfire building standards. But after the heavy property losses of the Black Summer, the challenges of building bushfire-resilient homes are becoming clear.

At QUT’s Wind and Bushfire Laboratory, engineers are looking for ways that building elements might be compromised during a bushfire to allow embers to get inside. Their laboratory has its own furnaces that they use to test defences such as walls and shutters.

Their data is also used to develop models that can be used to better understand how heat is transmitted across surfaces.





there are still surprises, he adds – like the duration of the Black Summer bushfires and a fire season “that’s not defined by the worst couple of days within it, but by the fact that there wasn’t actually weather that allowed the fires to go out, even with the support of the fire agencies”.

“It’s like, ‘Well, gee, that wasn’t part of the modelling assumptions,’” Leonard says. “So you’re actually having to learn those lessons, and then go back and unpack the weather and the way we interpret it in new ways to actually deal with it.”

HUMANS

In a single, terrible day in 2009, 173 people died from bushfire. Black Saturday – 7 February – was the deadliest-known bushfire day recorded in Australian history. Months of hot, dry conditions and record-breaking heatwaves in Victoria had sucked the moisture from the landscape. When sparks from power lines and human hands ignited flames, the resulting blazes ravaged 450,000 hectares of land and 3,500 buildings in just 24 hours.

More than a decade later, the Black Summer spanned almost the entirety of the spring and summer of 2019 and early 2020, from the first major bushfire outbreak at Gospers Mountain in NSW on 26 October 2019 to the three-day

The Tanami Desert is home to the largest Indigenous Protected Area (IPA) in the country: 10.16 million hectares, bigger than the state of Tasmania. The majority of the Southern Tanami IPA is on Warlpiri country, and is managed by Warlpiri rangers. One of their major concerns is patch burning (above) to rejuvenate country, create wildlife habitat and reduce the intensity of bushfires.

torrential rainstorm starting on 7 February 2020 that extinguished most of the bushfires threatening the east coast.

During that time, bushfires burned through more than 24 million hectares – an area slightly smaller than the United Kingdom – destroyed more than 3,000 buildings and incinerated over a billion animals and birds. Thirty-three human lives were lost.

Given the scale of the fires, and their incursion into populated areas such as the NSW Blue Mountains and Mallacoota, Victoria, the fact “that we didn’t end up with [a] Black Saturday-type fatality list is a sign that something is different,” says Richard Thornton, former CEO of Natural Hazards Research Australia, who has been working in the bushfire science field for nearly three decades.

What had changed in the decade between Black Saturday and Black Summer was an understanding of why people died in bushfires, and what could be done to prevent those deaths.

In 2012, a team of CSIRO scientists, including Leonard, analysed more than century of data on human and building loss during bushfire. From 1901 to 2011, 260 recorded bushfires were associated with at least 825 deaths and the destruction of around 11,000 homes. The data came from a variety of sources, including the Australian Fire

Authorities Council's fire fatalities database, official inquests, royal commissions, coroners' reports and even news stories. Its collection was part of a bigger effort to centralise information about house and life loss during bushfires in Australia, into what is now called the Attorney General Department's National Fire Danger Rating System (NFDRS) Life Loss database.

The richness of that data varied enormously depending on the source. In some cases, all that could be gleaned was that there had been a fatality associated with a fire. But other sources gave information about where the person was when they died – for example, inside a house or car, or



**60% OF PEOPLE WHO DIED
IN BUSHFIRES [FROM 1901
TO 2011] DID SO WITHIN
SIGHT OF THEIR HOMES."**

out in the open – and whether their death was the direct result of exposure to flame, heat and smoke, or as a consequence of the event, such as from a heart attack or drowning.

The analysis of the century of data revealed one particularly sobering fact: 60% of people who died in bushfires did so within sight of their homes – including 2/3 of those who perished on Black Saturday – and 80% were within 500m of their homes. The numbers suggested a story of many choosing the traditional 'stay and defend' approach to bushfire – they stayed to fight, then, as the beast roared nearer, realising they were in mortal peril, they tried to flee, and they died.

The study also suggested that around 2/3 of those deaths happened inside buildings and on days where the conditions met the criteria for what is now labelled "Catastrophic".

That data, and the reams of evidence presented to the Black Saturday Royal Commission, led to a major shift in the messaging around what people should do in bushfires to keep themselves safe.

"The old 'prepare, stay and defend policy' was put under challenge with the Black Saturday Royal Commission," Thornton says.

But it wasn't completely defeated.

"It could have ended up that the Royal Commission had said, 'No, you've just got to mass evacuate' like they do in the United States," he says. Instead Australia moved towards a middle ground. The message is now that the safest choice is to



Richard Thornton,
Natural Hazards
Research Australia



leave early. But in the case that some still choose to stay and defend, the advice is to be well-prepared and confident in their ability to keep their head amid the frenzy of a bushfire. The decision to stay or go has to be made well ahead of the bushfire's arrival, perhaps before one has even ignited if the conditions are bad enough.

And this is where our psychology can be our undoing, particularly the human need to see something with our own eyes to truly believe it. Research suggests that in uncertain situations such as bushfire, people hesitate to act based on a single source of information, even a trusted one. The recent revision of the Australian Fire Danger Rating System down to just four categories (Moderate, High, Extreme and Catastrophic) was informed by a survey of more than 5,000 Australians to better understand how to



communicate the risk to lives and property should a bushfire ignite on that day and in those conditions. The new categories – particularly Catastrophic, which comes with tagline of “For your survival, leave bushfire risk areas” – leave no room for uncertainty. Similarly, the revised alert levels – Advice, Watch and Act, and Emergency Warning – are clear in their messaging about the urgency of the threat.

“It’s getting really pointy messaging around ‘now it’s definitely too late to leave the area,’” Leonard says. “That’s a massive improvement and, in a sense, embraces that idea that there’s certain things you can’t control, and you have to actually admit that to be able to issue a warning like that to a community.”

But there is an elephant in the room. Should people be living in areas where these high-level

Every year, nearly 200,000 Australians volunteer with our six state and two territory bushfire services at great personal risk. There’s the immediate physical danger – radiant heat can exceed 150 kilowatts per square metre, while the human pain threshold for heat is around 2 kw/m² – but smoke also poses an insidious threat. Data is coming in, but the long-term effects of firefighting are still not well understood.

warnings are likely to become more and more commonplace in a hotter, drier Australia?

As an accredited bushfire planning and design consultant at CR Bushfire in Sydney, and former town planner in flood-prone areas of the UK, Catherine Ryland is well acquainted with the threat that extreme weather events pose to infrastructure, especially homes. Her post-graduate dissertation focused on applying the precautionary principle to building in flood-prone areas, and she says, “really basing our decisions less on housing need and housing demand, but more on hazard risk and getting the planning right for the risk base.

“So it was very interesting then coming into the bushfire space 20 years later and encountering very similar issues in the way that risk is dealt with in the planning system.”

When she started working on bushfires, Ryland says everything to do with bushfire mitigation was focused at the level of individual buildings and houses, “rather than looking at land release and saying, ‘is that land actually appropriate to build on, and can we mitigate the risks?’”

That is starting to change. Both the Black Saturday and Black Summer Royal Commission reports highlighted the need to look closely at the viability of suburban expansions and ensure that new homes aren’t being built in areas where the bushfire risk is too high. Councils are now taking a more strategic view of where and how people build in bushfire-prone areas.

But it’s still a long way from a comprehensive policy, or even from an understanding of what bushfire-strategic land planning looks like.

“There has been a huge amount of change in terms of the way we can model risk for bushfires, so that obviously has given us more information to be able to play with in terms of actually identifying where the risk might be too high for certain areas,” Ryland says.

Knowing the risk is one thing. Deciding what to do about it, especially amid a housing shortage, is a whole other issue, and one that local and

When this photo (below) was taken in January 2020 near Mount Adrah, NSW, 135 fires were burning across the state. 20 people had died and nearly 2,000 homes had been destroyed. 2019 was the hottest and driest year on record for Australia, but 2023 may break that record, bringing worsening fire conditions. While governments, emergency services and the community are better prepared, the data suggests that our individual decisions during a bushfire are also critical to saving lives and property.

state governments will increasingly have to consider when deciding where Australians live.

One thing is abundantly clear: after three consecutive years of La Niña, bringing wetter, cooler summers to the east coast, a horror summer fuelled by climate-change-amplified weather systems – El Niño and the Indian Ocean Dipole – awaits. Already the early warning signs suggest that the relationship between Australia’s people and ecosystems, and fire, is about to take a turn for the worse.

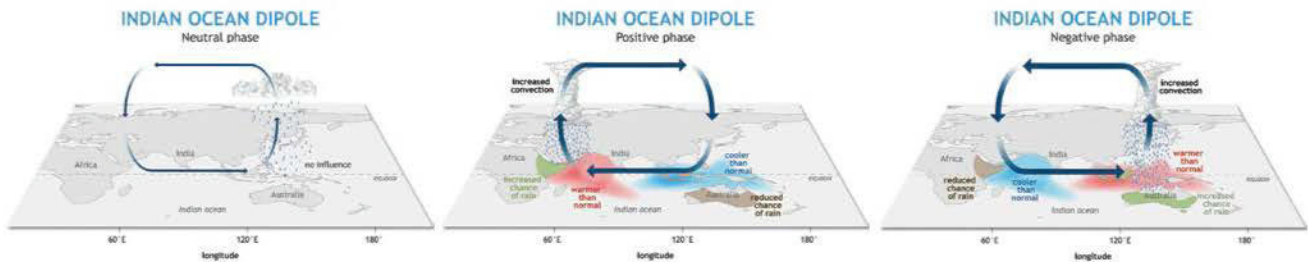
ECOSYSTEMS

If you can’t beat ’em, join ’em. That’s how Australian plants deal with the inevitability of fire on this hot, dry continent. Fire will come, whether ignited by lightning or human hands, so plants such as the old man banksia have evolved not just to survive fire but to require it. Even Australia’s fauna has learnt to live and even thrive with fire; in the case of the brown falcon, deliberately seeding fires to flush out prey from their grassland burrows.

But just like humans, Australian flora and fauna are facing a new challenge from climate change, which is altering the frequency, intensity and distribution of fire in the landscape.



New phases: Indian Ocean Dipole explained



Along with human-caused global warming, the extreme conditions of the Black Summer were made possible by natural climate patterns such as a strong positive Indian Ocean Dipole (IOD). A key driver of Australia's climate, the IOD can be thought of as the cousin of ENSO in the Pacific. Just as El Niño and La Niña bring Australia dry and wet weather respectively, the IOD influences wind, temperature and rainfall patterns across the Indian Ocean according to its phases: neutral, positive or negative. These phases are determined by the differences in sea surface temperatures. A positive phase, for example, occurs when cooler conditions in Southeast Asia are contrasted with warmer conditions in the western tropical Indian Ocean. This results in less moisture in the atmosphere northwest of Australia, often leading to less rainfall and warmer temperatures.

On 22 December 2019, the Gospers Mountain bushfire burned into Blackheath, in the Blue Mountains. What had been lush – albeit desiccated – sclerophyll forest, thick with the smooth white trunks of mountain ash rising above dense tea tree and banksia shrubbery, became a grey and black moonscape.

Barely a fortnight later, there were signs of recovery: burgundy-coloured epicormic growth sprouting from the charred bark of a eucalypt, a flash of green emerging from the blackened top of a grass tree.

This bit of Australian bush was lucky. The fire that burned through on 22 December was relatively calm, meandering through the dry undergrowth in low winds and mild temperatures. It was also the first bushfire that had burned this ground in many decades. Many regions incinerated by Black Summer were not so lucky.

The concept of a fire regime is key to understanding a bushfire's impact, says fire ecologist Rachael Nolan from Western Sydney University. "The regime is not just fire, a binary 'yes/no'," Nolan says. "It's how frequent the fire is, how severe the fire is, is it understorey fire or overstorey fire, what season the fire is, how big the fire is – because that could affect if you have little patches of refugia for animals to escape in."

Added to that list is the question of how fire regimes are changing. This process has occurred since the continent first formed, and in more recent times with the landscape management practices of First Nations people. But now there's climate change.

"What we can say is that generally a lot of our ecosystems are burning more frequently than



Rachael Nolan,
researcher in fire and
plant ecology,
Western Sydney
University

they have been with the historical record," Nolan says, acknowledging that the historical record doesn't go back all that far.

Bushfire ecologists talk about "interval squeeze", a term coined in a pivotal 2015 paper published in *Frontiers in Ecology and the Environment*. It projected that climate change and the associated increase in bushfire, heat and drought would "narrow the fire interval window compatible with population persistence", meaning that just as plants are requiring longer intervals between fires to recover from more intense fires, those intervals are shortening due to climate change. The paper warned that woody plants, such as eucalyptus, were on a trajectory towards increased extinction risk, especially in areas forecast to become warmer and drier.



UNLIKE A HOUSE OR A COMMUNITY, IT'S DIFFICULT TO PROTECT AN ENTIRE FOREST OR ECOSYSTEM FROM BUSHFIRE."

Eight years later, one of its co-authors – David Bowman, a professor at the University of Tasmania – is watching those predictions come true. The Victorian Alps, for example, have burned twice in the past decade while also dealing with drought, and the combination is taking a visible toll.

"The trees are really on the ropes, and these are the notoriously tough eucalypts," Bowman says. "There's a lot of dead trees."

Bowman believes it's evidence of ecological collapse, and that's just one example. "Some vast percentage of the world's eucalyptus forests [are] in this amazingly precarious state, and now we're going into an El Niño with climate change and [a positive] Indian Ocean Dipole," Bowman says. "It's terrifying."

Bowman knows better than most how Australian ecosystems are changing with more frequent and intense bushfire seasons coming on the heels of droughts and heatwaves. As a pyrogeographer – a title he co-opted after being accused of being a scientific dilettante "just flitting around doing all this stuff" – he brings his interests in archaeology, anthropology, eco-physiology, climatology, forest ecology, fire management, human health, epidemiology (and possibly others) to the challenge of understanding and adapting to bushfire.

"I needed a framework, and pyrogeography is a framework," he says. "It's understanding fire in space and in time, and understanding humans as a central agent, and understanding recursive



David Bowman,
pyrogeographer,
University of Tasmania

“FIRE IS SOMETHING THAT WE’LL ALWAYS BE CHALLENGED TO BETTER UNDERSTAND, RESPECT, EMBRACE, EVOLVE WITH.”

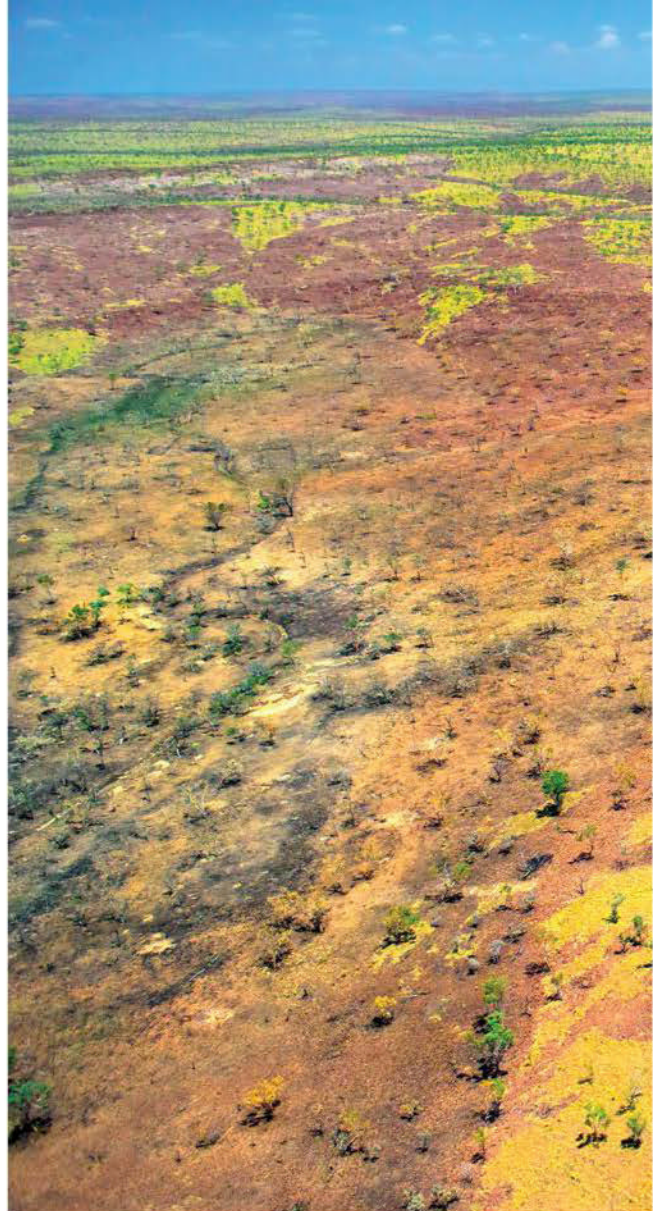
relationships amongst all the elements of that relationship.”

Bowman's research spans from studying how bushfire activity has varied across the southern hemisphere over the last 10,000 years, to studying how stalled policy on bushfire bunkers is creating a barrier to fire adaptation.

This involves “lots and lots and lots of field work, lots of analysis, and then there's a critical point where you have to read incredibly widely, and start absorbing huge amounts of information,” Bowman says. “It involves continent-scale and global-scale analyses in collaboration with experts in fields from molecular ecology and mathematical modelling to geospatial statistics and law.”

Alarming, his work has revealed that in response to climate change, the Australian bush is experiencing a sort of wildly oscillating adolescence.

“Because the climate's changed, the amount of carbon in the landscape – which is the fuel – is disproportionate, it's in disequilibrium, and so that has to be removed in some way,” Bowman



says. “The simplest way to remove it, because of climate change, will be through fire.”

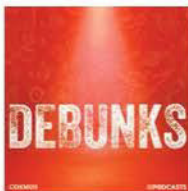
Woodlands, like the eucalypt forests of the Blue Mountains, are likely to undergo increasingly traumatic and extreme boom-and-bust cycles of regrowth and fire, but what comes at the conclusion of that – what equilibrium will look like – is likely some form of ecological collapse that will produce a very different vegetation landscape.

What will happen to any particular forest is an open question, but some warning signs are emerging, according to Nolan. “We're not seeing eucalypt species going extinct or anything like that – it's more that the structure of the vegetation or the way it looks is changing,” she says.

If that sounds benign – like the forest simply rearranging the furniture – it's not. As forests change, becoming less dominated by large trees and shifting towards smaller trees, shrubs or even grassland, that ecosystem's ability to store carbon plummets.

Unlike a house or even a community, it's pretty difficult to protect an entire forest or

Want to learn more
about bushfires?
Check out our new
podcast *Debunks*.





ecosystem from bushfire. But across Australia's northern tropical grasslands, which stretch from the Kimberley in the west to Cairns in the east, Indigenous rangers, pastoralists and scientists are, quite literally, fighting fire with fire.

Indigenous cultural burning practices are returning to these landscapes, and non-Indigenous Australia is learning from them. As the fuel loads in the vast savanna grasslands build up, so-called 'cool burns' are being used to get these areas under control early in the fire season, when moisture ensures the fires will be less intense and easier to control.

But choosing where to do cool burns in such a vast landscape to maximise the benefits is difficult. NAFI – the North Australia and Rangelands Fire Information website – provides one solution. Run by Charles Darwin University (CDU) since the early 2000s, NAFI is a near-real-time fire-mapping resource that uses satellite data to create maps of areas that are burning or have burned, down to a resolution of around 250 sq.m per pixel, with higher resolution in some areas.

The savanna grasslands of the Marion Downs Wildlife Sanctuary in the Kimberley, WA, regenerate in sweeping patterns after a fire.



Peter Jacklyn,
ecologist and NAFI
manager, Charles Darwin
University

"Anybody who really is interested in managing these large areas of land that are in this open country needs to know where the fires are and what areas have been burned," says Peter Jacklyn, a tropical ecologist and NAFI Service Coordinator at CDU. "If it's been burned yesterday, there's not going to be much grass there at all; if it burned three years ago, there's going to be quite a bit."

Those burns may be the result of bushfires, cool burns by Indigenous rangers and custodians, by landowners, or by fire or parks authorities. Those groups use NAFI to plan when and where to burn to reduce the risk of the big, intense, greenhouse-gas-spewing bushfires of late summer. Cool burns can be used to protect vulnerable areas and ecosystems by creating low-fuel barriers around them, and they are also a source of carbon credits if they then reduce fire emissions overall.

"Across that far northern belt of Australia, the frequency particularly of fires that occur late in the dry season ... has dropped right off and these are where these carbon projects are," Jacklyn says.


Here, fire is a tool: one that can be used to nourish landscapes in the way it has been done for tens of thousands of years.

LOOKING FORWARD

The relationship between Australia and fire is not over. It never will be. It might be going through a tough time right now, but that will change again as science, society and culture seek to find some sort of equilibrium in a system in flux.

Over the course of a decades-long career in bushfire science, CSIRO's Leonard has observed and studied that changing relationship. "It's actually an inevitable and important aspect of the environment we live in and something that we'll always be challenged to better understand, respect, embrace, evolve with," he says.

Fire only cares about three things: energy, oxygen and fuel. It won't change as long as the laws of physics still hold. It's humans, living in the Anthropocene – and the Pyrocene – who must adapt. And we are.

"From a societal perspective, I see [us] slowly transitioning from 'we can conquer it, we can conquer anything as a society and all we need is the right amount of resources and clever ways to activate it and get on top of things'," Leonard says, "moving to a reality where you recognise that it's not possible to completely control [fire] and that a holistic approach is needed to manage, prepare for, limit the destructive nature of, and utilise it as an effective tool." 

BIANCA NOGRADY is based in the Blue Mountains. Her last story for *Cosmos*, on CubeSats, appeared in Issue 89.

Friends *of the* Red Handfish



When your neighbour is struggling,
the community rallies around them –
even if that neighbour is a fish, writes
Keely Jobe.

The Friends of the Red Handfish (FORH) organise their first community information session for a Monday night. It's a modest affair, held in a Besser-block community hall with fluorescent bar lighting and teal nylon seats. There's tea and biscuits, cheese and crackers, and a raffle with donated prizes. But an hour before the event is set to start, the weather arrives. Furious winds and drenching rains barrel in sideways. It's the kind of night for staying in bed and watching Netflix, not for sitting in a community hall listening to a science lecture on a fish.

Setting up her PowerPoint, our special guest Dr Jemina Stuart-Smith only laughs. She's a marine biologist at the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS), and coordinator of the Handfish Conservation Project. "If no one shows, at least we'll have the pick of the biscuits," she says.

Pam, a member of FORH, turns to me as we unstack the chairs. "If we get 10 people I'll be surprised," she mumbles.

But 45 minutes before it's due to start, the first family arrives, followed by a steady stream of locals. By 7pm, the carpark is full, we've run out of chairs and it's standing room only. Despite the weather, despite the school night, half the community have turned up to hear about the red handfish.

SOON AFTER I MOVED to the small coastal community in which I live, my neighbour Tracey invited me to join Friends of the Red Handfish. I was wrapped in a towel after a mid-summer snorkel and Tracey was busy in the garden. She told me about a colony of this critically endangered fish that inhabited a patch of the shallow rocky reef bordering our suburb. "You probably just swam over them," she said.



FORH had been founded a few years before when Tracey and her partner Siobhan started making scones and tea for the IMAS divers in return for handfish gossip. They met Jemina, a regular diver keen for community engagement. Tracey told me that FORH was gathering members with the aim of gently spreading community support for our elusive aquatic neighbours.

I had heard of the red handfish. I knew their numbers were drastically low and the likelihood of extinction alarmingly high. To have them settled in waters I could see from my living room felt like a gift, a great privilege. It also reminded me that my local patch was not only unique and complex but already well established. If I wanted to call this place home, if I wanted to consider the non-human lives that had settled in the area before me, I had some learning to do.

THE FIRST FORH MEETING I attend is held in Pam's living room. A dozen of us gather around a table spread with an obscene amount of baked goods, and everyone holds a cup of tea. Pam's greyhound Russell oversees proceedings. Some actions are already in the planning, from putting up signage at the boat ramps to hosting a morning tea for funding bodies to having a handfish sculpture placed at the suburb's entrance. Marley, our youngest member at nine years of age, presents a brilliant drawing of a handfish and it's decided this will be the mascot.



The handfish team (above) at the University of Tasmania's Institute for Marine and Antarctic Studies. From left: Tyson Bessell, Jemina Stuart-Smith, Ness Delpero, Andrea Williamson and Andrew Trotter. Anyone can sponsor – and name – captive handfish (below), which will be released into the wild.

The community information session is the next big thing on the menu. If the species is to survive in our area, it will need the support of informed, protective human neighbours.

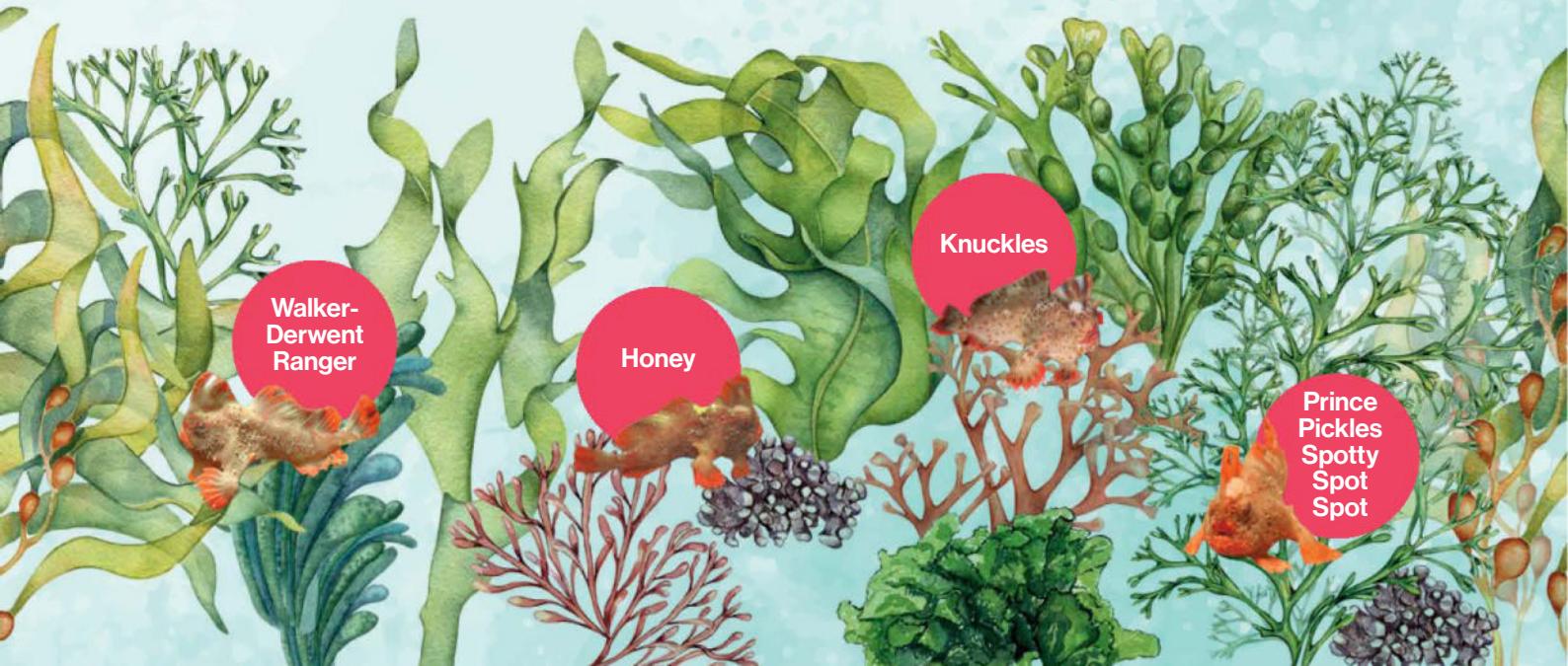
Local elder Auntie Colleen Mundy/minungkana has plenty of ideas to get feet in the door. "What about a raffle?" she offers. "What about a meat tray? Or a bottle of wine?"

"And how many people are we catering for?" Markus asks. "Should we say 40?"

"The local supermarket is donating a cheese platter," Pam informs us. "So that'll bring the costs down."

Jemina is also there, updating us on the research. There are certain details the scientists are still unsure of, like how to tell the difference between the males and females of the species, how to recognise mating behaviour or environmental triggers, and why the fish are (only just) surviving in this particular spot. The data is hard to come by because there are so few individuals left. This is the first time I learn there are only seven fish in our local colony, which stuns me. I knew they were endangered, but SEVEN!?

THE RED HANDFISH (*Thymichthys politus*) is an angler fish endemic to the south-east waters of Tasmania. They are demersal, meaning they live largely on the seabed, and they have no swim bladder, relying instead on agile pectoral fins to grip and move themselves about, essentially walking on the ocean's floor. Despite this quirky trait, handfish barely move and prefer the world,



food included, to come to them. In fact, over the course of a lifetime – thought to be around five years – red handfish might travel only a few metres from where they hatched. This stagnant existence might seem like an obstacle to evolutionary fitness, but the red handfish has a surprisingly long lineage, dating back to the Eocene Period, 56 to 33 million years ago.

Today, due to a raft of interconnecting threats, these fish have a grim outlook. Habitat loss due to warming waters, an increase in native sea urchins, residential run-off, overharvesting of lobsters, and in-shore anchor dragging have reduced and fragmented the population. Once relatively common, they are now restricted to only two sites in Frederick Henry Bay, about a half-hour's drive east of Hobart, with the total wild population sitting at roughly one hundred individuals. The smaller colony is located where I live.

But there is hope. While most of these threats are caused by human interference, when it comes to the survival of the red handfish, human engagement is now the most effective method of conservation. Beyond subsurface interventions such as urchin culls, lobster reintroduction and habitat restoration, researchers like Jemina can only do so much. Care at a practical level involves



Red handfish – usually no more than 10cm long – have won over the Foundation for Australia's Most Endangered Species, which is funding a four-year program to assist with captive breeding, ecosystem restoration, pest species management and – hopefully – a world first: teaching captive-bred fish to survive in the wild.

“Who better to make room for the crucial work of researchers, while offering local knowledge, than those who live in the area?”

a change in recreational fishing behaviours, in boating behaviours and, hopefully, in broad community support for a future in-shore marine park, which will do wonders for habitat restoration. These are not small requests in an isolated coastal community where differing opinions are rife regarding how the water should be used. Changing attitudes will take time and patience.

“The community has to want it,” Jemina says. “They’re the deciding factor regarding the project’s success.”

Fortunately, community support is growing. Xavia, one of FORH’s younger members at 11 years of age, is thrilled to live so close to the species. “Knowing that Tasmania is the only place you’ll find these creatures, I just think we’re the luckiest people to live right beside them,” she says.

Marley is more visionary in his hopes for the species, predicting a population boost of

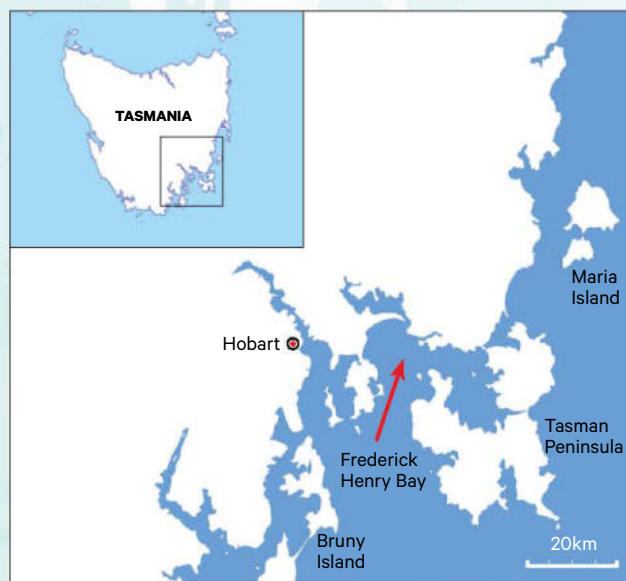
“thousands and thousands”. It might be the fragility of the colony that brings FORH together, or maybe we imagine a brighter future for the species and its habitat. We’re a motley crew with not much more than coastal suburbia in common, but the red handfish is something we all agree on.

“I have never seen a handfish, despite them living within a hundred metres of our front veranda,” Siobhan says. “But I don’t need to see them to care about them or love them. They are symbols of the struggle many of us face in life. They are champions of survival and can teach us about resilience. I will always have their back.”

Pam agrees. “I have always felt a huge weight of sadness that we, as human beings, brought about the demise of the thylacine,” she says. “I could not stand by and let the same thing happen in my community. Red handfish survival is linked to all our survival.”

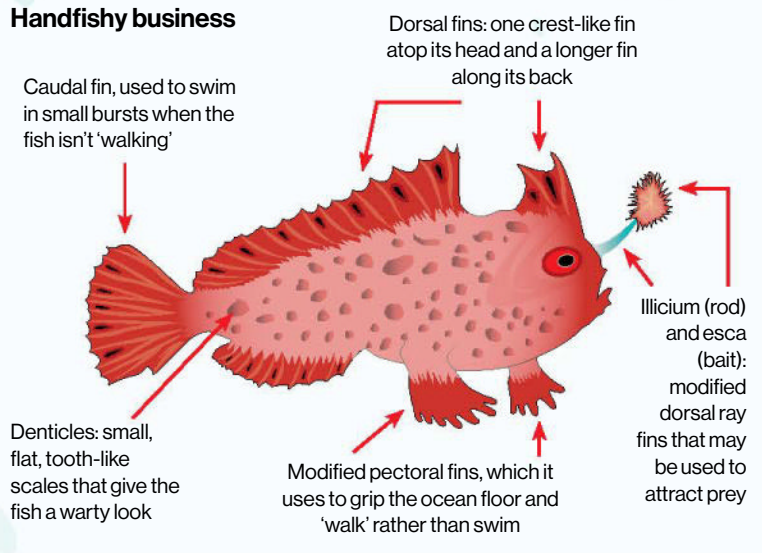
WHEN THE RED HANDFISH CAPTIVE breeding program opens its facility, Jemina invites a few members of FORH to the event. She wants us to see in person what our efforts are going towards. Pam, Aunty Colleen and I drive over to represent the group and find the facility in a leafy coastal suburb on the outskirts of Hobart, tucked between a football oval and a bowls club. The centre is packed with scientists, students, philanthropists and higher-ups at the university. We feel a little out of place, but Jemina introduces us as if we’re honoured guests.

The captive red handfish are kept in a dimly lit storage cupboard the size of a pantry; more than 100 are scattered between roughly 20 tanks. The fish are fed with locally sourced amphipods and monitored seven days a week. Every day the



MAP: GREG BARTON. TOP LEFT: JEMINA STUART-SMITH.

Handfishy business



tanks are cleaned, the water quality and temperature checked. There are more fish in these tanks than can be found in the wild – they are the hope of the species' survival. Some of their kin have already been released at sites with extant wild populations. When they come of age and size, this group is set to join them.

I can't stop staring at the fish. I am totally smitten.

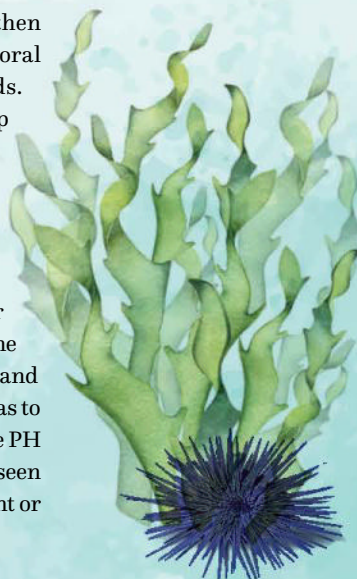
"They're beautiful," Auntie Colleen whispers.

They're bright vermilion or light pink with red mottling, and sport wicked peachy mohawks, orange fins, bright blue eyes. Above their heads, a fluffball flamboyantly dangles. Their lips, invariably pulled down in a pout, are so plump it's as if they're filled with Botox. Some of the fish are fully grown, around the length of an adult's thumb. Others are babies and no bigger than a fingernail. Settled on the bottom of the tanks, the fish are so still they could easily be mistaken for decoys or even bath toys. But every now and then one will shift, open its large, dexterous pectoral fins and crawl forward as if on primate hands.

What strikes me about this backroom set-up is its modesty. While the aims and ambitions of the sciences are generally lofty and their findings invariably complex, the day-to-day running often sits somewhere between the predictable and the mundane. This is the case with the captive breeding program run by Dr Andrew Trotter and his small team. Someone has to feed the fish, so someone has to go out and catch the tiny crustaceans they eat. Someone has to clean the tanks, get rid of the fish poo, check the PH levels, check the temperature. This is the unseen side of science and conservation. It is not elegant or even particularly intellectual. It's just labour.



Interested in lending a helping hand (or naming a fish)? To find out more about the Handfish Conservation Project, head to handfish.org.au



AFTER THE INFORMATION night has ended, Jemina, Pam and I have a quick debrief over the cheese platter. Over 50 names have been added to the FORH email list. We're a bit stunned by the range of attendees: young families, retirees, old locals and new locals, weekenders, recreational fishermen, aquaculture workers and local councillors. More importantly, we're bowled over by the response from community, by the enthusiasm and pride for the place where we live.


Jemina's talk – which included a slideshow of local marine species, an introduction to the red handfish and its conservation status, and a description of the role community can play in saving it – was met with rapt attention, murmurs of recognition and agreement. When she was done, the questions came thick and fast, and the meeting ran over by half an hour.

Some locals had no queries, wanting simply to relay their fears. They bemoaned the changing coastal habitat, noting the destruction they'd witnessed. Some recalled a time when throwing a line out meant reeling in dinner. Encouragingly, there was unanimous appetite for improving the local marine environment.

I can see Jemina is relieved by the response. Researchers rely on local support and local voices to advocate for their findings and implement their ideas. This grassroots approach, though possibly daunting to researchers, makes total sense, because in a community whose identity and daily activity is directly linked to the sea surrounding it, there's little chance an outsider, however well informed, will hold as much sway as a local voice.

And who better to refuse a species' extinction than its community? Who better to make room for the crucial work of researchers, while offering local environmental and cultural knowledge, than those who live in the area? Who better to get other locals on board than their neighbours?

When the hope of an entire species is gathered in a single converted storage room the size of a walk-in wardrobe, when they're fed seven days a week with food gathered by hand from nearby bodies of water, it leaves the door open for all kinds of everyday acts of conservation. It means anyone can, and should, get involved.

Sometimes conservation is making scones and tea for divers. Sometimes conservation is a letterbox drop, or a donated cheese platter. Sometimes it's booking the local community hall and making sure the percolator is full and the biccies are stocked. Sometimes conservation is putting the chairs out. And anyone can do that. 

KEELY JOBE is based in Tasmania. This is her first story for *Cosmos*.

Birds do it, bees do it – even humans instinctively understand and respond to vectors, such as when we catch a ball or take a shortcut. But as **Robyn Arianrhod** explains, the deceptively simple concept of vectors took a long time to find its mathematical language, and it is now offering surprising discoveries in ecology and neurobiology.

Right line fever

Anyone with a veggie patch or a fruit tree knows that insects can be a pest. They can also transmit diseases – mosquitoes, for instance, can carry malaria and encephalitis, among many others. These diabolical disease-carriers are called vectors.

But this story is about a different kind of vector – a happier one that carries not disease but a line from point to point. (The word *vector* comes from the Latin *vehere*: to convey.) Surprisingly, insects play a role in this story, too. For insects aren't just pests. They're a vital part of the ecological food chain, and they pollinate many of our food crops. Their populations are declining around the world, and in the hope that we can reverse this

before it's too late, these little creatures are finally being recognised for how environmentally important they are. But they've also become famous for their brains, and it's in those tiny brains that this vector story begins.

In carrying out its precious pollinating, an insect buzzes about from flower to flower on a twisting journey in search of food. Yet it always finds its way home again – and remarkably, by the most direct route. In other words, no matter how tortuous its foraging path, it knows how to make a beeline for home. This extraordinary behaviour has been found in a variety of insects – notably bees and ants – and in various birds, animals and even shrimps. But how do they do it?

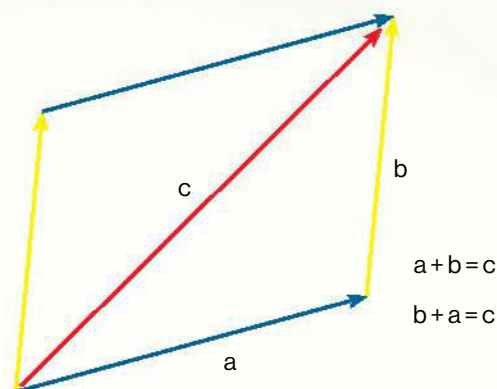


Astonishingly, they use a neurological form of mathematical vector arithmetic. As they meander along, these navigating creatures keep track of their course by adding vectors of the happier kind – the kind mathematics students learn to represent as an arrow, because mathematical vectors can encode both distance and direction. The arrow points in the required direction, and its length gives the distance.

Humans can do innate navigational maths too, of course. We can even do it in advance, by instinctively visualising the shortest distance between two nearby landmarks – for example, when deciding to take a shortcut across a paddock from point A directly to a farm gate at C, instead of following the boundary track from A to B to C. This is just the kind of thing that insects do, when they forage from A to B to C, then calculate \overrightarrow{AC} . By reversing direction, this becomes their ‘home vector’, \overrightarrow{CA} , which tells them how to make their beeline home.

If you studied vectors at school, you’ll recognise that the length and direction of this shortcut route is found from simple vector addition, adding up the arrows from A to B and from B to C via the triangle or parallelogram rule (above right). This rule says that any two vectors can be aligned tip to tail like this, and their sum will be the vector along the diagonal of the implied parallelogram.

In practice, of course, there are many more than two points on an insect’s journey, and at each new point it updates its distance vector by adding the new leg of the journey to the



previously calculated cumulative vector. We’ll see just how clever those navigating birds and bees are shortly, but let’s put first things first. Although neurobiologists have shown that we and other creatures have an innate sense of vector maths, this is reverse engineering in hindsight. First, mathematicians had to invent vectors! It’s one thing to do something instinctively, and quite another to figure out what’s going on in a general, conceptual sense.

The winding road to vectors

In fact, learning to think abstractly has been a long journey for human mathematicians. Even the humble parallelogram rule was a long time coming – and it is more sophisticated than you might think at first glance. That’s largely because it embodies the idea of a vector having independent components. For example, when a vector **c** is composed from the sum of the independent vectors **a** and **b**, they can be thought of as the components of **c**. Sounds simple, doesn’t it? Yet 500 years ago, some of the best

An insect buzzes about from flower to flower on a twisting journey in search of food. Yet it always finds its way home again – and remarkably, by the most direct route.

mathematicians in the world had trouble with the parallelogram rule – and therefore with the idea of independent components of motion, as you can see in the way they struggled to determine the shape of the path of a projectile.

Unfortunately, the impetus for this research was war, and the problem of precisely targeting an enemy with cannonballs, bullets and arrows. The 16th century Italian mathematician Niccolò Tartaglia was the first to take a serious shot at analysing the path of a cannonball. All he had at his disposal were his imagination and any data he could glean about how high and how far such a ball would go; there were no technological tools to visualise the trajectory as a whole. So he reasoned with his intuition, arguing that the cannonball would follow a straight line in the direction it was fired, until gravity slowed it down so much that it curved around and then simply dropped straight to the ground.

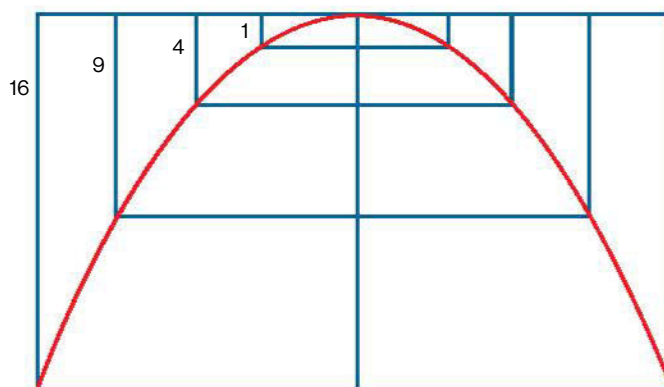
You can see that this is not the right shape for a tennis ball's trajectory, for example: if someone hits it across the net, it doesn't drop straight down but arcs over to the other side of the court. But cannonballs are heavy, and most people back then assumed that heavier objects fall faster than lighter ones. So Tartaglia's reasoning seemed to make sense.

It was another half century before two of the greatest minds in early modern science – Galileo Galilei and Thomas Harriot – independently solved the problem in the early 1600s. In fact, they solved two problems. First, without air resistance, heavy objects don't fall faster than lighter ones – this is the law of free fall, which Harriot and Galileo expressed as an equation relating the distance fallen to the time of fall, and they showed that this is the same for all bodies falling under the same gravitational force. Second, without air resistance all projectiles trace out a parabolic path.

These were thrilling discoveries, especially when you remember that Harriot and Galileo were doing this from scratch. To find the law of free fall, they dropped balls of various weights from various heights and timed how long they took to fall to the ground. To figure out projectile trajectories, they took empirical evidence from newly published gunner's manuals and meticulously fitted curves to this data. Then they worked out the theory.

They had little concept of vectors, but they glimpsed the idea that resistance-free projectile motion is made up of two components, each acting independently together (unlike Tartaglia's vertical component acting by itself). For a horizontal shot, for example, there's the constant horizontal

Harriot's vector vision



Harriot's point-blank trajectory: The law of inertia, formally laid out decades later in Newton's *Principia*, is represented by the equal horizontal spacing of the vertical lines, indicating that the horizontal component of velocity remains constant (equal horizontal distances are travelled in each unit of time.) The law of free fall is represented by the horizontal line spacing, showing that the vertical distance fallen is proportional to the square of the time of fall (simplified here to 1 unit of distance fallen after the first second, 4 units after 2s, etc). The result is a parabola.

velocity due to the shot, and the accelerated vertical motion due to gravity. When Harriot and Galileo combined these two independent motions graphically they showed, with beautiful simplicity, that the trajectory is parabolic (see above).

Today, with vectors in hand, high school calculus students can easily deduce this shape – for any angle of projection, not just a horizontal one – by resolving the force acting on the projectile into its horizontal and vertical components and then applying Newton's second law of motion to each component.

In his legendary *Principia* of 1687, Isaac Newton had not only developed the laws of motion, he'd also used the parallelogram rule to study physical quantities such as forces or velocities. In fact, it was Newton who first clearly identified the two-fold nature of force and velocity – a nature that in hindsight we can call “vectorial”, because he defined these quantities in terms of two attributes: direction and magnitude. Vectors wouldn't get their name, and all their mathematical rules, until the 19th century. But as we'll see in the rest of this story, the Newtonian idea, along with a bit of trigonometry, is perfectly good enough for us to understand how those remarkable insects find their way home.

Tiny brains, trailblazing skills

Bees are not only experts in making beelines home. Once back in the hive, a bee knows how to tell its mates the location of any delicious and abundant food source it has discovered on its foraging trip. It does this via its amazing waggle dance, where it orients its body to give the direction (calculated relative to the Sun), with the duration and number of waggles communicating the distance.

External cues such as the position of the Sun are particularly useful in enabling insects and other creatures to monitor their direction of travel, but navigation also involves a purely internal method called path integration (PI). This is a process that uses the body's internal movement cues to keep track of changes in direction and distance so that the insect can find its way to a given point – back to its starting point, for example, or from its hive to a known food source. And keeping track of direction and distance means keeping track of a vector.

Our brains can do this, too. I've already mentioned our ability to visualise shortcuts, but when the lights go out unexpectedly, we can still navigate our way across the room to the cupboard where we keep matches and candles, feeling our way around the furniture but also using internal PI to gauge the distance and direction.

It was Charles Darwin who first hypothesised the existence of navigational PI. In a letter in *Nature* on 3 April 1873, he noted that indigenous North Siberian travellers were able to keep to their course for long distances over icy terrain, even when they had to detour around geographical pitfalls, and when there were no stars to guide them. He suggested that all humans can do this – if not always to such a marvellous extent – by unconsciously calculating all the deviations we encounter along the way (see box, right).

The internal cues used for PI include balance and muscle signals, which offer a kind of in-built step counter. So counting steps is not just a fad for humans with mobile phones (which contain sensors, such as gyroscopes and accelerometers, that mimic physiological ones): it is the only way that some insects, such as desert ants in a featureless landscape, gauge the distance they've travelled.

Other creatures, such as honeybees, determine distance using "optic flow" – the relative motion detected by the eyes as visual images whizzing past, or by animal whiskers or insect antennae detecting air flow. This internal sense of motion gives an estimate of speed, which is integrated with respect to time to produce the distance.



VECTORS AND DEAD RECKONING

Darwin suggested path integration (PI) might be analogous to dead reckoning. This term derives from the way mariners deduced their distance and direction of travel across open seas – deduced reckoning became "dead reckoning". A sailor would tie evenly spaced knots in a rope, one end of which was tied to a log and thrown overboard. As the ship moved away, the log effectively stayed put;

by counting the number of knots as the rope uncoiled, the sailor knew the distance travelled. He also knew the compass direction and the speed (in knots!) from the number of knots unravelled in a given time. In this way he could constantly update the ship's position. This is analogous to physiological PI, where the brain progressively updates the body's position vector.

At least, that is how maths students would do it: $\int \frac{dx}{dt} dt = x$ (plus a constant, although this is zero if the distance is calculated from the origin). Some researchers suggest that insect and other brains can do this literal calculus too. For example, in a 2020 paper showing that the decline in navigational ability in older humans is related to increasing errors in estimating velocity, former UCLA post-doc Matthias Stangl and co-authors defined PI as “the integration over time of a self-motion estimate, in the strict sense of vector calculus, to maintain an updated estimate of one’s position and orientation while moving through space”. And in his review of PI research, Thomas Collett, from the UK’s University of Sussex, defined it this way: “At an abstract level, the process of PI consists of adding up all the oriented lengths of segments along a path” – that is, adding distance vectors – “or equivalently, of integrating an individual’s velocity vector over time”.

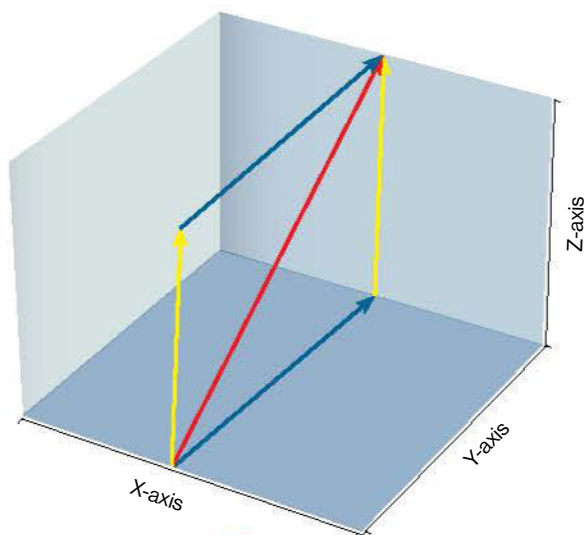
Talking about vector addition and calculus is a way for us humans to get a handle on the extraordinary navigational ability of various species. But how mathematically sophisticated can a tiny

Fruit flies are not navigational superstars like bees, but it seems that their brains, which are the size of a poppy seed, really do know how to do vector mathematics.

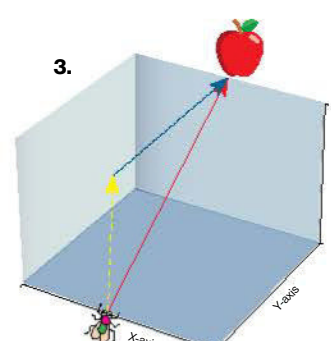
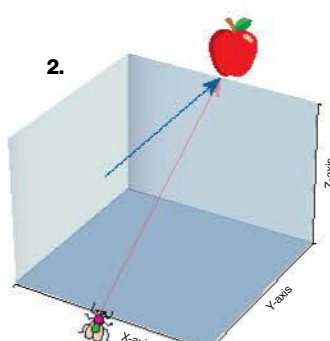
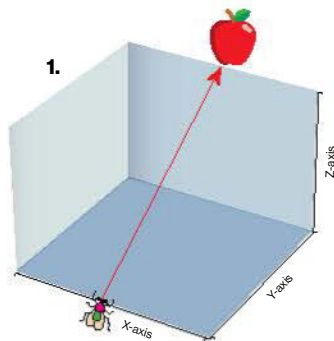
brain be? For a long time, researchers assumed that this mathematical language was more analogical than actual. In recent years, however, neuroscience has progressed dramatically – for relatively simple brains, at least. For instance, fruit flies are not navigational superstars like bees and desert ants, but they still know how to get around – and it seems that their brains, which are roughly the size of a poppy seed, really do know how to do vector mathematics (see below).

Of course, like other insects, birds and animals, fruit flies do not draw arrows to represent their vectors. Just how they do it had long been a tantalising mystery, but in 2021, two groups of neuroscientists found the answer. Cheng Lyu and

Vectors: the third dimension



Research suggests that other species can perform sophisticated navigational vector calculations. The image on the left takes the parallelogram vector (red) and places it in a 3D Cartesian coordinate frame. Below, in the fruit fly’s frame of reference at **1.**, in order to achieve the target apple, the fly needs to take into account conditions like wind (**2.**), and set its flying course accordingly (**3.**). Of course, if the wind is blowing in the opposite direction, it might need to find a different fruit. In practice, research suggests that fruit flies can navigate in a highly complex way, using four component vectors and making constant adjustments in response to external cues.



Gaby Maimon from the Rockefeller University, Larry Abbott of Columbia University, and Harvard's Jenny Lu, Rachel Wilson and their team identified the neurons that enable fruit flies to perceive motion (through optic flow). The activity of these neurons – PFNd and PFNv cells – can be measured, with peaks or bumps occurring when the relevant neurons are active because the fly is on the move. But here's the amazing thing: when these activity bumps are plotted across all the PFN neurons in the fly's brain, a sinusoidal pattern emerges. The amplitude of this sine wave represents the fly's speed, and the phase gives the angle or direction of travel. Ergo, it represents a vector!

Turning this velocity vector into a home vector happens downstream from the activity of the PFN neurons, but already the fruit flies are doing vector maths. Their field of vision is almost 360° , and their brains have four sets of these motion-sensing neurons – and four sine waves measuring their activity. Between them they encode the insect's motion in the forward left and right directions, and similarly for the backward directions. In other words, these four sets of neurons encode the components of motion in these four directions.

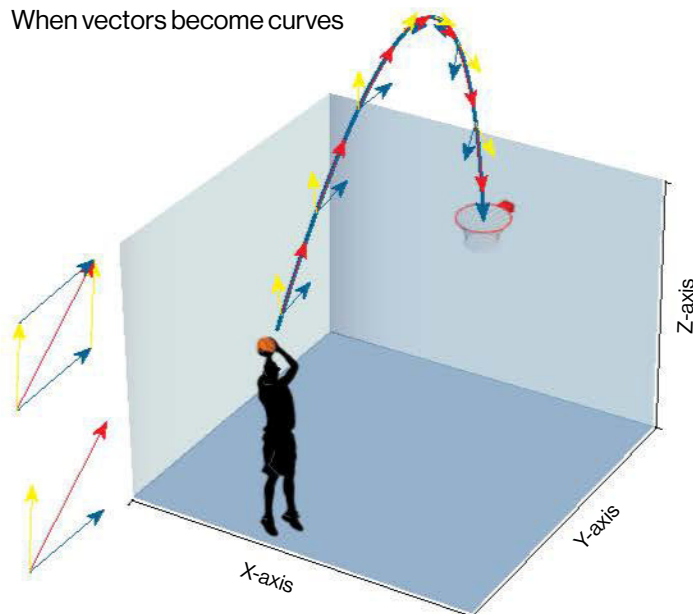
But here is the really incredible thing. These four PFN vectors give the velocity components with respect to the insect itself, but this information is then fed into another set of cells, called hAB neurons, which also have sinusoidal activity patterns. This time, though, these sinusoidal waves represent the velocity vector relative to an external cue such as the Sun. To achieve this, the neural circuitry in this tiny speck of a brain has performed another amazing mathematical feat, effectively rotating the original four component vectors so that they are now aligned to the angle of the Sun. Then the insect's brain adds up these rotated vector components – not by using the parallelogram rule, but by adding sine waves.

"[W]hat's happening here is an explicit implementation of vector math in the brain," explained Maimon in an interview for Rockefeller University. "The result is an output vector that points in the direction the fly is travelling, referenced to the Sun" – just as sailors once oriented themselves with respect to the Sun and the stars.

From one brain to another

This kind of transformation from one reference frame to another – from the fly's to the Sun's in this case – is widespread in science. For instance, it's fundamental to the physics of relativity. It also happens inside your mobile phone step counter. A common step-counting mechanism involves

When vectors become curves



Parabolic movement – such as firing a cannon or throwing a ball – can be visualised as a series of velocity vectors constantly updating, as the object moves subject to gravity. (Other external forces, such as air resistance, will skew the parabola.)

calculating the vertical acceleration of your heel as it strikes the ground. So, while the fruit fly needs to know its direction of travel relative to the sun, your phone needs to calculate steps in your (Earth-centred) walking frame, where your body is the vertical axis and the ground is the horizontal one. The phone-centred frame, however, is usually rotated compared with the Earth frame, depending on the orientations the device might take in your pocket or bag. The phone's program uses a mathematical transformation from its own frame to yours so that the step counter chooses the correct vector components – the vertical ones due to your heel strike – from the raw, often random data collected by the phone's sensors.

To take just one more tech example, this same kind of fruit fly mathematical toolkit, with its vector additions and geometric rotations, enables orientation and tracking in the artificial navigation systems that guide ships and robots.

The search is on to identify exactly how human brains enable us to navigate – in the hope that this might help improve diagnosis and treatment for people whose spatial skills have suffered due to injury or dementia. It's an enormous task, given that a fruit fly brain has about 150,000 neurons in total, and we have around 90 billion. But the work on fruit flies is an exciting first step, by suggesting the way that insects

neurologically do this navigational vector maths. Similar work has been done on bees, by an international team of researchers that included Thomas Stone and Barbara Webb from the University of Edinburgh and Rachel Templin, then at the University of Queensland.

Other researchers have also noticed that brain cells sensitive to direction have sinusoidal activity patterns, although not in such detail as the recent fruit fly research. In 2023, Pau Aceituno, Dominic Dall'Osto and Ioannis Pisokas – researchers at Einstein's old school, ETH Zurich – reviewed all this evidence. They then explored various mathematical models for encoding direction, concluding that the sinusoidal one seen in various insect neural circuits is not merely a coincidence. Rather, it has evolved as the most noise-resistant arrangement – that is, the one that is least prone to errors as the data is encoded neurologically.

Mysteries of maths and magnetism

Speaking of evolution, Darwin declined, for lack of evidence, to speculate as to whether other creatures are better at innate navigation than we are. In the insect world, it's hard to beat those clever bees for navigational prowess, but other species are also experts – and migrating birds certainly have an advantage over humans. For a start, they inherit from their parents the direction they need to take on their annual migratory journey. To keep track of this direction, though – when the wind blows them off course or when they stop off to eat or rest – they use not only the Sun and stars like an ancient mariner, but also Earth's magnetic field. Researchers, including biophysical


LIVING THE VECTOR DREAM

Recent research adds substance to the idea that navigation in humans and other creatures involves both external cues, such as the Sun or natural landmarks, and PI. Christopher Anastasiou and Naohide Namamoto from Queensland

University of Technology, and their colleague Oliver Baumann from Bond University, showed that we learn the layout of a landscape better if we actively walk it – using our own internal sense of motion – rather than remotely studying a map or a video.

chemist Peter Hore from the University of Oxford, UK, and biologist Henrik Mouritsen from the University of Oldenburg, Germany, have discovered evidence suggesting a quantum mechanism that enables birds to 'see' these fields – and it, too, makes use of vectors: in this case, the spin vectors that represent the magnetic moments of elementary particles.

The physics of this discovery – and how it may give birds their own inbuilt magnetic compasses – is complex. So is the detail behind the fruit fly's vectorial brain waves and all the other studies on PI. But it all owes much to the abstract mathematical language of vectors. So does much of the technology neuroscientists use to make their discoveries. For instance, spin vectors are key to structural and functional magnetic resonance imaging (MRI and fMRI), which allows researchers to observe the structure and function of the brain.

So, while the navigational prowess of insects, birds and animals is truly amazing, it is utterly awesome that we humans can go beyond this innate form of mathematical ability. It's been a slow journey, as the work on projectile motion illustrates. But ultimately, mathematicians have created the abstract language that has helped scientists unravel not just some of the brain's secrets, but many other mysteries of the universe. 

ROBYN ARIANRHOD is a mathematics affiliate at Monash University. Her book, *Vector*, is due out in 2024.

A satellite image of the Mediterranean region, showing the Italian peninsula, Sicily, and parts of North Africa and Europe. A white outline traces the coast of Italy and Sicily. The word "MARGINS" is written in a large, black, serif font across the top left, and "CALL" is written in a similar font across the bottom right.

MARGINS

CALL

Goyder's Line has long formed the boundary between South Australia's crop belt and its hotter arid parts. Is climate change pushing the line south? There's no easy answer. Certainly, those living on its edges are getting a fast-tracked taste of a climate-changed landscape. **Rachel Williamson** talks to those on both sides of the line about what their future holds.

We're bouncing up the hill behind Andrew Bretag's 160-year-old home, through the gum trees, past the ewes that he jokes pay the mortgage on his 1,400-hectare farm, aiming for the million-dollar views at the top of the ridge.

We stop at the sandstone ruin known as Oakse's hut. Above us is the slow *whomp...whomp...whomp* of the single wind turbine on Bretag's property – another mortgage supporter, and part of the Hornsdale Wind Farm, which feeds Australia's first big battery.

We hop out of the ute and immediately I spot it: there, in the distance to the east.

"You can see it really well this year because it's been really dry – we're well below our rainfall averages for this time of year," Bretag says, tracing a line with his finger along the horizon where the cartoonish blue-green of wheat and canary-yellow of canola meet the golden grasslands beyond.

This is Goyder's Line, a geographic phenomenon pencilled onto maps in 1865 to show the edges of where rain reliably falls in South Australia. Goyder's Line starts hard up against the Victorian border a little north of Pinnaroo, 243 kilometres east of Adelaide. It curves up past Eudunda and Burra to Terowie before sweeping up between Yongala and Peterborough to form two peaks, one at Orreroo and the second at Mount Remarkable. The line descends southwards to Moonta and

finishes with an almost-afterthought slash of a pencil to bisect the Eyre Peninsula up to Ceduna, nearly 800km to Adelaide's north-west.

North and west of the line, rain is sparse and unreliable. To its south, precipitation averages 250 millimetres a year or better. This year and for who knows how long into the future, that boundary will be important: it's mid-September and the area is several days into an unseasonal heatwave. After a sodden 2022, Bretag's farm, Glenrest, has received just 45% of its average annual rain – and the dry season is already beckoning.

Andrew and Rhianna Bretag and their three children live just north of Jamestown, an agricultural hub three hours' drive from Adelaide that more than a century ago was home to one Reginald Murray Williams – the original RM Williams. They are on the "right" side of the Goyder transition zone: a lush agricultural area where crops are (almost) guaranteed for eight out of every 10 years.

Theirs is the side dotted with big gum trees. As the land recedes down the ridge and into the distance, the trees become squat and sparse. Water is the key ingredient in this land.

Climate change is not a factor for the people who work this area – yet. Tentative predictions of permanently hotter, drier weather are yet to manifest. But the Bretags can see from their dusty, toy-strewn verandah the drylands nibbling at the edges of the northern and eastern boundaries.

Thirty kilometres up the road, Peterborough is already living the hotter, drier future.

"If we haven't got water, we can't exist," says Ruth Whittle, the town's mayor for the past 33 years. "We're north of Goyder's – we're in the drier area, so not so many people crop anymore, and it's getting worse. It's getting drier, hotter."

Peterborough is the counterpoint to Jamestown's agriculture-focused industriousness. It's tourist-town cute with ye-olde façades and part-time shopfronts filled with crafts. It's worked hard to build a tourism industry from its railway heritage, which appears to be paying off as locals and tourists jostle for parking spots on a sweltering Friday morning.

It relies on water piped in from the Murray River, almost 200km away, along with its rainwater tanks. But it's only a drought away from danger.



The two SA towns are a microcosm of our future. Whittle believes Peterborough is already living in a markedly changed climate; Jamestown can afford to kick the climate can down the road a little longer.

However, data is mounting that questions how much longer Australian farmers in these transition zones can continue to beat the odds. And while crops can run south, people and trees find it much more difficult to uproot.

Goyder's Line

The 1850s was a boom time for South Australian agriculture. A period of unusually wet years, combined with a surge in demand for food as neighbouring Victoria caught gold fever, drove men and their families further and further north in the nascent colony, searching for new lands for pasture.

But in 1864 those settlers got their first taste of the region's climatic whims. The great drought of 1864–66 exposed those who'd moved too far north, killing stock en masse and desiccating vegetation. Powerful dust storms skinned the land of topsoil.

With pastoralists crying out for rent relief, the government wanted to know the southern limit of the drought zones to define who got financial support, and who didn't.

Alone, on a horse, South Australia's surveyor-general George Goyder traversed the state. With limited rainfall records to lean on, he spoke to graziers and took cues from where saltbush, mulga and mallee grew. The result was a thick line across the state, mapping the 250mm

North of Goyder's Line, near Peterborough (above), SA, lower rainfall makes cropping impractical, and land is mostly given over to light grazing. A short drive south-east, in the Jamestown/Canowie Belt area (opposite top), better rainfall generally allows crop planting in eight out of 10 years. Sheep are bread-and-butter to the region's farmers, but it's crops that bring the cream.

rainfall isohyet (the line that joins points with the same amount of precipitation): the distinguishing line between arid and semi-arid zones – and one of the most famous incarnations of climate as a defining edge.

Global warming creates both fear and fascination for climatic transition zones like Goyder's Line. The fear is that the line is moving south. It's a boundary based on climatic conditions, so it seems logical to assume that if the climate changes, that boundary will change as well. Right?

Around the world many such lines exist – and they're on the move. Researchers suggested in 2018 that the 100th Meridian in the US – the line notionally splitting the country between arid western grasslands and humid eastern plains – might be shifting east. But the researchers said global warming played only a minor role. In North Africa, the Sahara has been expanding at an alarming rate – based on rainfall, by about 10% between 1920 and 2013, with the starkest impact being Libya's shift from mostly semi-desert to mostly desert over that time. One culprit is the "tropic squeeze", a phenomenon where the wet tropics are getting narrower and the dry edges are expanding; over-grazing and poor land management are also to blame.

The tropic squeeze is having an impact on Australia's own transition zones. In 2018, US and UK climate scientists used satellite imagery to show the edges of the tropics have been moving polewards at a rate of 44km a decade since 1979. Warmer global temperatures are energising the Hadley cell circulation system (see page 90), which means the hotter air at the equator rises



higher and travels further towards the poles than it once did.

“This expansion has intensified the subtropical ridge over southern Australia, pushing cool season mid-latitude storm tracks further south, leading to a reduction in winter rainfall and run-off across the region,” wrote CSIRO researcher David Post, lead author on a 2014 study on what it will mean for water availability in Australia.

Projections from CSIRO’s Climate Change in Australia website forecast “with high confidence” that winter and spring rainfall in the Burra-Orroroo corner of Goyder’s Line will fall by as much as 15% by 2030, as seasonal storm systems move south.

So is Goyder’s Line shifting south? Well, it’s complicated.

Moving target

In a 2012 paper taking a look at the limits of SA’s grain-growing areas, CSIRO’s Uday Nidumolu and his co-authors traced a new line, which ran to the north of Goyder’s, based on a measurement of the ratio between rainfall (P) during the growing season (April–October) and potential evaporation (E) of 0.26. If the 1865 line is the limit of reliable rainfall, the researchers found that the 0.26 P:E isopleth (a line on a map connecting points at which a given variable has a specified constant value) is the dry margin, “hard edge” of the Australian grain belt.

“The surprisingly close fit of this ratio with much of the Australian grain belt suggests a climatically determined hard edge to the cropping zone,” they wrote. “If this finding is correct, it follows that a warming and drying trend will shift

the 0.26 P:E isopleth and hence the edge of the grain belt towards the coast.”

But regions protected by hills, such as the area stretching from Burra right up to Mount Remarkable, and areas with microclimates and different soil types are likely to see smaller changes. In 2012, even the worst-case-scenario model predicted 2050 as the year that isopleth line reached the Goyder’s current position.

“There’s such significant natural year-to-year variability in rainfall, but also important

The fear is that Goyder’s Line is moving south. It’s a boundary based on climatic conditions, so if the climate changes, that boundary will change as well. Right?

decade-to-decade variability,” says co-author Peter Hayman, from the South Australian Research and Development Institute. “However, when you read the summary of climate models it seems to be that a warmer world is a wetter world, except in the mid-latitudes. So I tell my farmer friends this is likely true, except where you chose to buy or inherit a farm.

“In terms of rainfall I am increasingly comfortable in saying I don’t know.”

Back at the Bretag kitchen table, Andrew pulls out a green, hardcover exercise book containing the farm’s rainfall records dating back to 1868. We pore over them, noting his mother’s careful notes marking occasional snowfall and

totting up some of the later years that had been missed in the maelstrom of farm life.

The numbers are weird: rainfall at Glenrest farm is trending *upwards* over time. I check the BOM data for Jamestown and it's the same.

But the very last number in the book shows how changeable this land can be. An average year sees 432mm of rain. By 17 September 2023 – a day on which temperatures soared above 30°C very early in the long dry season – Glenrest had recorded only 197.5mm of rain since the start of the year.

The rainfall issue, then, is not how much – but when. And it's not the only thing driving change along Goyder's Line, and throughout Australia's crop-growing regions.



Wheatfields (above) in the Jamestown/Canowie Belt area produced record yields during the 2020–22 triple-dip La Niña.

Boom and bust

If sheep (and, for a lucky few, wind turbines) provide a farmer's bread-and-butter income every year, when it rains wheat delivers the cream.

"Cropping is boom or bust," says Martin Clark, who farms next door to the Bretags and has a reputation for an elephantine memory for weather.

"You get a frost or a dry year like this and your yield reduces. But we can go from an average of three tonnes of wheat per hectare to last year's record of five and a half. It's just phenomenal.

MIND THE GAP

The wheat yield gap is the difference between what farmers are currently harvesting, and the amount that could be achieved using the best adapted crop varieties with the best land management practices. Calculations on CSIRO's Yield Gap Australia website are based on 15 years of data (2000–14) – a period long enough to account for climate variability but short enough not to be greatly affected by technology and climate change. Data includes ABS crop production figures and crop simulation, weather and soil-type data.

Former CSIRO researcher and yield gap expert Zvi Hochman says the yield gap data is bad news.

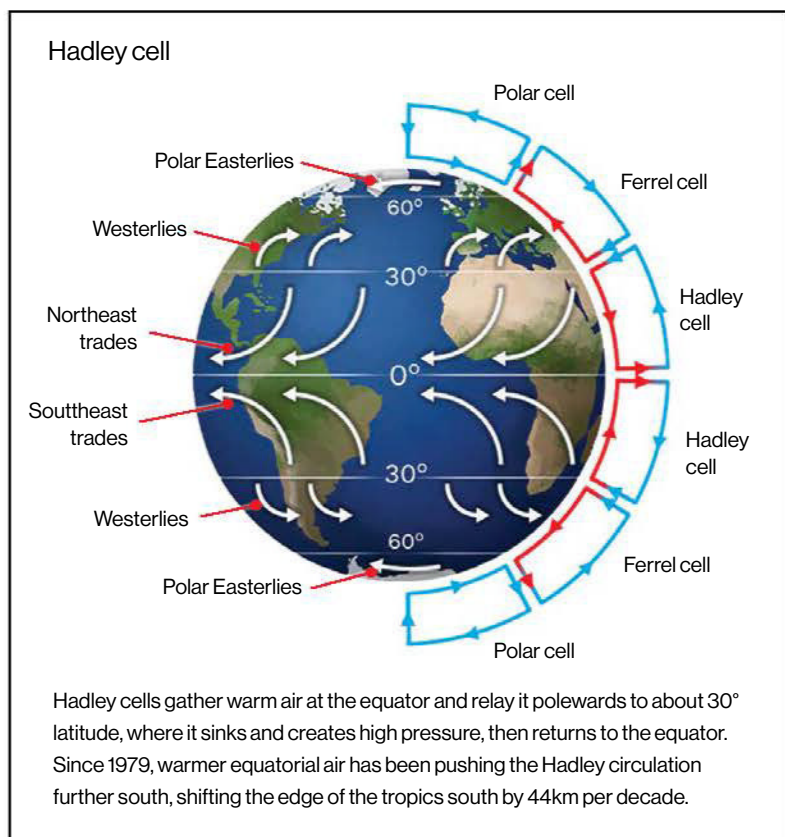
Papers Hochman wrote in 2017 and 2021 show that water-limited wheat yield – how much it's possible for farmers to grow given access to water, or lack of it – fell from 4.4 tonnes per

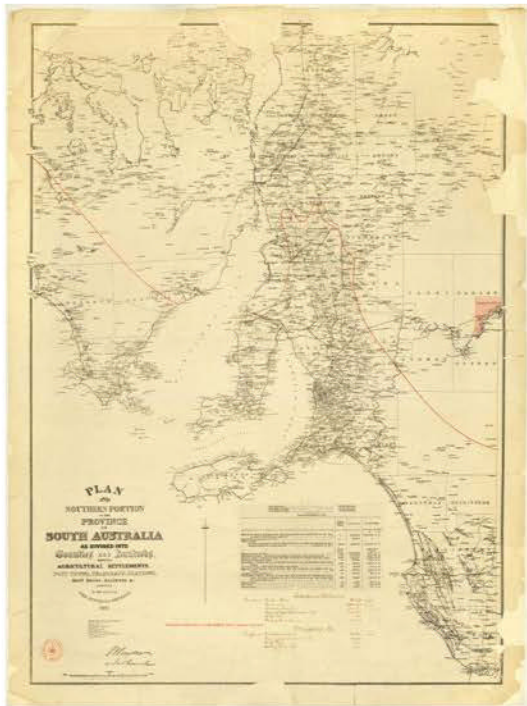
hectare in 1990 to 3.2 tonnes in 2015.

The Yield Gap Australia website shows Jamestown's average yield gap is 51%: farmers are getting an average of 2.4 tonnes per hectare, but their water-limited potential is 4.8 tonnes.

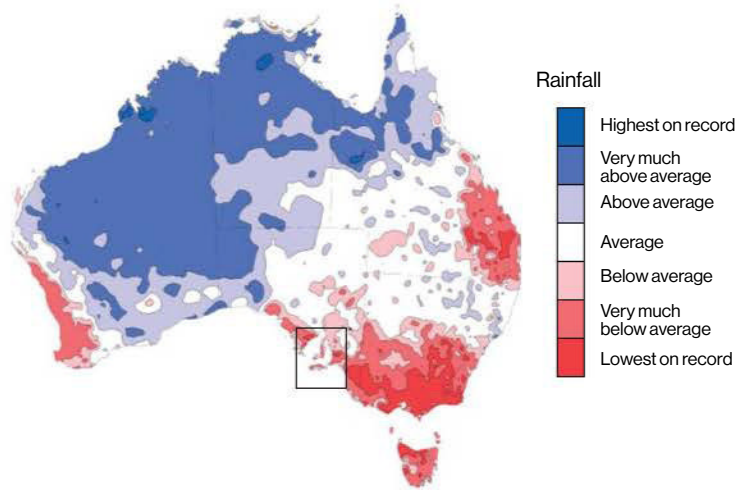
Hochman's 2017 paper lays out the underlying numbers. Genetics delivers a 0.5% annual yield boost; extra carbon dioxide in the air adds another 4%. But lower autumn and winter rainfall accounts for 83% of the water-limited yield decline; higher temperatures prompt the other 17%: if a wheat plant's florets (small flowers) form in temperatures over 30°C they'll be sterile, and in 20–25°C temperatures plants mature too fast and grow fewer seeds.

To top it off, the WHO says high ozone levels, caused by hot ground-level temperatures, caused 2–5% of wheat crop loss in southern Australia last year.





Change in Australia-wide rain distribution



Australia-wide rainfall distribution for 1997–2009 compared to long-term climatology (1900–2010). The land area covered by Goyder's Line – in box – all rates below average rainfall compared to long-term records – in some parts considerably so.

Last year's the biggest grain year I've ever seen in this country."

Australia produced a record almost 40 million tonnes of wheat in 2022, according to the federal Department of Agriculture, Fisheries and Forestry. The grain is critical to the livelihoods of Aussie croppers. It's the country's biggest food export. Last year it was our seventh largest export good overall – just ahead of crude petroleum. Even though lentils are an up-and-comer and canola is pure money, wheat is the easiest to grow and hardest.

"Whether Goyder's Line has moved, I don't know," says Clark. "Weather's a long game. If you came here spring this time last year and said, 'Do you think it's moved?', well, what do you reckon? There's bloody rain. We were getting a hundred mil a month for three and a half months."

What Clark knows for sure is that he's producing more with the same amount of rainfall, as a result of new moisture-conserving farm practices such as reduced tillage and improved soil and temperature monitoring.

Elsewhere in Australia, this isn't true. Rainfall in cropping areas has fallen by 1% a year since 1990 and in the south-east, rainfall in the critical months of April and May is down 25%, says former CSIRO researcher Zvi Hochman – point-man on the country's wheat yield gap (see "Mind the gap", opposite).

Agronomist Darren Pech agrees that, so far, changing practices are doing more with less.

An 1880 plan (above left) of southern South Australia shows Goyder's Line of rainfall. SA's surveyor-general George Goyder did the on-ground research for the line in 1865. Good rainfall in most years between 1867 and 1875 prompted many farmers to crop north of the line, but many were forced to abandon their land when "normal" rainfall returned, vindicating Goyder's choice.

Sitting in his Jamestown office, Pech tells me that moisture conservation measures – such as spraying summer weeds – which ease dependency on seasonal rainfall, are probably the biggest game changer.

It's only 8.30am but through the window, the main road – RM Williams Way – is already shimmering in the heat.

"And there's a thousand other things," Pech adds. "Controlled traffic, where they're driving on the same wheel tracks all the time to try and minimise soil compaction. A greater reliance on phosphate and nitrogen inputs. A big increase in weather stations with moisture and temperature probes."

Those practices safeguard moisture gifted from summer storms, which used to be lost to evaporation or wind as farmers repeatedly tilled soil for weed control. Massive boom sprays, machines that punch individual holes in the ground to sow seeds and harvesters that follow GPS-set paths all preserve soil texture – a boon for Jamestown's red clay soils, which only grudgingly give up moisture when dry or tightly compacted.

These innovations also change the soil microbiome, as more organic carbon in the ground gives microbes a better chance to tolerate heat.

Whether improved farming practices will be enough to overcome rising temperatures and all their complex affects, only time will tell. "Farmers are paddling harder and staying on the same



spot,” Hochman says. “It’s not universally true, but nationally it’s true.

“Technology is enabling us to maintain actual yields on a steady keel and maybe even a slight increase, but we’re not seeing the dividends from all the technology improvements that we would see if the climate wasn’t squeezing us to the degree that it is.”

Across the line

The price Peterborough pays for its low rainfall is living on the financial margin. It’s a town where people do find it easy to uproot and move away.

Without a strong agricultural economy, the town’s heyday was in the 1950s, when as a railway hub for steam engines it supported 5,000 residents. Town elders even thought it was headed for big-city status, says Peterborough newsagent and historian Chris Woodman. They clearly forgot the cautionary tale of Lancelot, a neighbouring town that was in the running for the rail industry but missed out: by the 1930s all that was left of it was a cemetery and some building ruins.

Peterborough’s industry slowly eroded as rail switched to diesel engines; the last

Young trainspotter Mark Noble (above) watches dual 600-class locomotives (‘double header’) haul on the Cockburn Line, about 10km east of Peterborough. The Cockburn Line linked Broken Hill with Port Pirie for 84 years, until 1970. Peterborough was an administration and service centre for South Australian Railways; at its peak, about 1,500 people were employed in its railway workshops, which today house the Steamtown Heritage Rail Centre’s collection.

passenger train left its station in 1986. The population has dwindled to 1,600 people, half of whom are retirees or welfare beneficiaries, with a median income almost half the national average. State and federal grants make up as much of the Peterborough council budget as rates.

Mayor Ruth Whittle is open about the challenges those facts present. She’s lived through the town’s peak and its decline: she was born there, and has been mayor for the past 33 years. In her office, a stack of Australian flags and boxes of files line the back wall; the temperature is mercifully cool as heat begins to radiate off the pale sandstone buildings that line the main street.

“Our big thing now is tourism,” Whittle says, leaning back in her chair. “We’ve had to work hard at it. It was always there. People always wanted to see things, but we didn’t take too much notice of it. We didn’t have to. We had an industry and tourism didn’t matter.

“Then, suddenly, we didn’t have an industry.”

But Peterborough’s biggest worry is water. Bureau of Meteorology (BOM) records for the town go back to 1881 and the data shows rainfall is trending down.

"Everyone is worried about what happens on the eastern seaboard, as far as all the water that is going into cotton farms and all the other farming, because it means the water is not coming into the Murray River," Whittle says. "We depend on Murray water. There are aquifers underneath us but they're getting low."

"We belong to the Murray Darling Basin Commission – we're stuck out here in the middle of nowhere, and yet we belong to a river commission! Which to me is always funny. We've got to try and fight the good fight all the time and keep that water coming down the Murray."

Thus Whittle looks east. Farmers to the south look at their weather stations, and scientists gaze at satellite data and computer models. But the first

"If you have a plant type that requires a microbial community to perform, and a changing climate changes that, then of course that vegetation will disappear."

signs of how climate change might affect transition zones could be underground, in the rainforest beneath our feet that a group of Swiss ecologists estimates contains 59% of all life on Earth.

The life subterranean

A thin skin of soil covers our planet. It's home to a vast variety of organisms, from fungi to bacteria to plants, vertebrates and mammals that live underground. Earthworm excrement – castings – boost soil fertility and texture; fungi breaks down organic debris to make nutrients such as carbon, nitrogen and phosphorus available, as do bacteria. Soil viruses help with microbial evolution and population. Some, like fungi, are tailored to wetter soils. Others, like actinobacteria, are one of the first to jumpstart after a long dry.

This complex system is as vulnerable to booms and busts as crops, says Gupta Vadakattu, a senior researcher at CSIRO, as rainfall becomes more episodic between periods of hotter, drier weather.

"If you have a plant type, let's say, that requires a microbial community to perform, and a changing climate changes that, then of course that vegetation will disappear from the native systems in different ways," says Vadakattu. "One example would be most native systems plants are dependent upon what's called mycorrhizal fungi, the bridge between soil and the roots that help moisture uptake and phosphorus and other nutrients."

Harsh heatwaves, such as the September event I'm caught in, can be catastrophic for soil.

"A field study spanning 18 years found microbial efficiency was reduced at higher soil temperature, with decomposition of recalcitrant, complex substrates increasing by the end of the period along with a net loss of soil carbon," wrote the multiple authors of "Scientists' warning to humanity: micro-organisms and climate change", published in 2019 in *Nature Reviews Microbiology*.

Forecasts for hotter, maybe drier futures are triggering new ideas on how to improve drought resilience or water-use efficiency in plants. One idea is transferring soil with dry-adapted microbial communities to locations without that same soil makeup, says Martin Breed from Flinders University, one of Australia's top soil science authorities.

That might become a crucial frontline as researchers try to protect the increasing acreage of agricultural land that will be in semi-arid locations, like those on the dry side of Goyder's Line.

The morning I called Breed from a carpark in Morgan, SA, was already 10°C above the mean daily temperature for the month. From inside my increasingly oven-like car, I asked him about how heat-baking will affect soils in places like Jamestown and Peterborough.

"In these semi-arid transition communities there's going to be all sorts of changes that we have not been measuring whatsoever where I would be absolutely certain that there would be species of microbes that are dropping off the post all the time," he says.

"I imagine there'd be all sorts of microbial communities that, under drier or hotter conditions, will start protecting themselves [by] no longer producing the compounds, the molecules ... that the plants and the animals would want."

"There's bound to be ripple effects on the plants and animals in those systems."

Is the world under our feet beginning to shift? We don't know. We're not sure, either, as to why the predicted march southward of plants and crops hasn't happened yet.

Does the future hold more Peterboroughs and less Jamestowns? "We've been [running] the farm now seven years," Andrew Bretag says. "It's not really long enough for us to really know, to try to work out [changing] averages. In 20 years time we might have more of an idea."

Peterborough mayor Ruth Whittle's take on outback town survival is much simpler: no water, no life. 🌵

RACHEL WILLIAMSON is based in Melbourne. Her story about solar power appeared in Issue 97.

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ZETT



▲ Iceland is layered with caves hollowed out in ice. Some are particularly chilly lava tubes or limestone caves, while others are formed in summer by glacier meltwater, which carves long tunnels and caverns beneath the thick ice sheets. Here, this world of Icelandic ice is countered by a fire spinner, bringing a spectacular orange glow to warm the space. According to archaeologists, fire – and orange – may have influenced our evolution. To learn more about this colour's history, turn to page 104.



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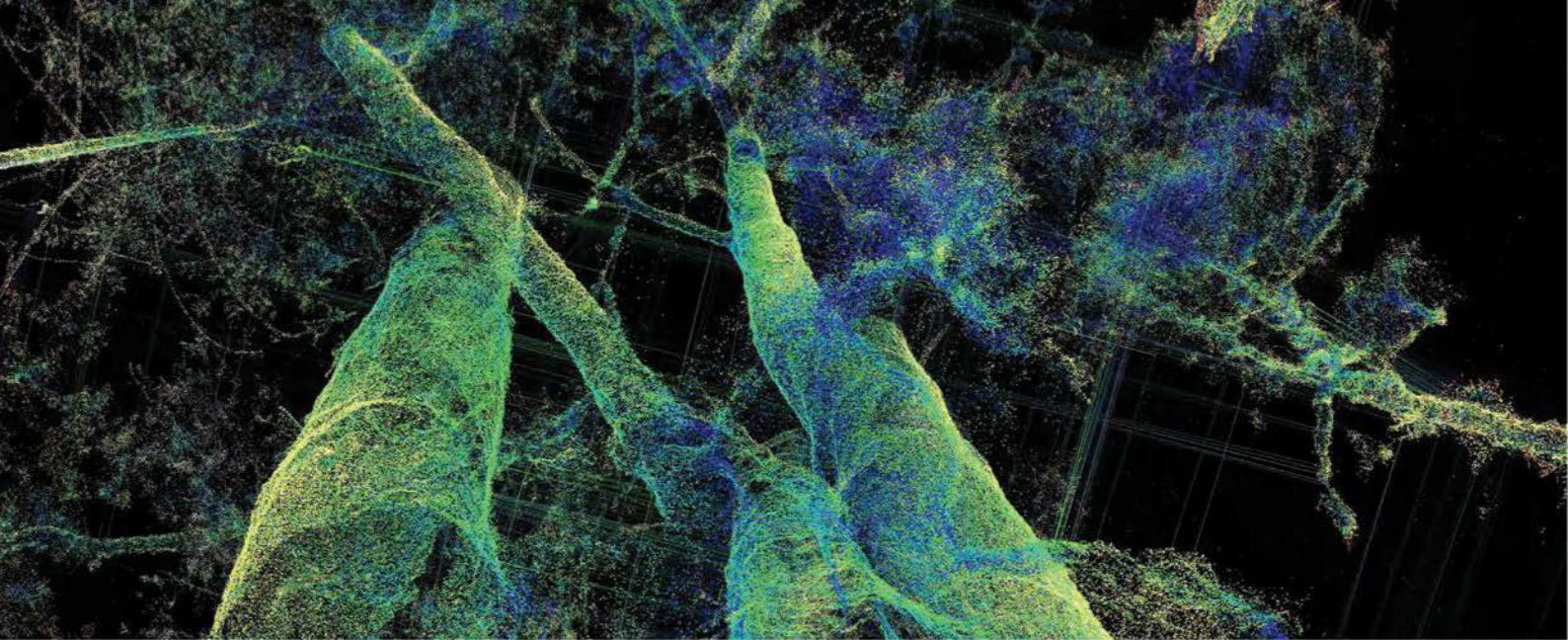
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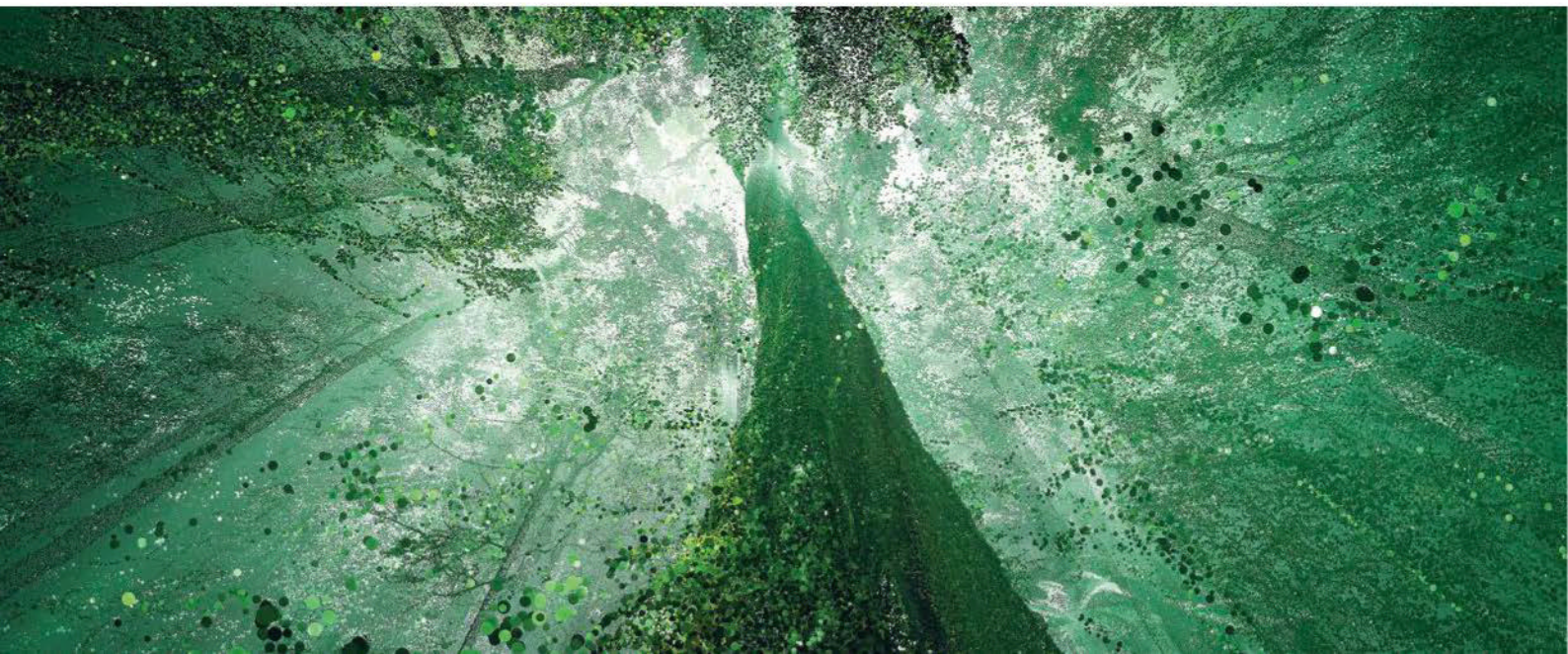
Protectors of the red handfish, siblings Xavia and Marley Furner.



GROWING **FORESTS** IN FILM



Tasmanian forests get the blockbuster tech treatment. **Amanda Yeo** explains.



The *Giants* opens with a crack of thunder, followed by a swirl of fiery colour. Motes of ember eddy and twist before coalescing into recognisable figures: a forest made of flames.

Though undeniably striking, the documentary's opening image isn't real footage of an actual bushfire. It's an illustrative animation, created using data collected through LiDAR scans more commonly used for forestry science.

A BIOPIC OF THE TREES

Released in 2022, Australian documentary *The Giants* examines the life of Robert James 'Bob' Brown – doctor, activist, environmentalist and first federal leader of the Australian Greens. While the film primarily focuses on Brown's activism and political career, particularly his rise to prominence during the campaign to save Tasmania's Franklin River in the '70s and '80s, *The Giants* isn't a straightforward biopic. Filmmakers Rachael Antony and Laurence Billiet recognised early on that it was equally important to highlight the magnificent trees Brown has spent his life fighting to protect.

"The decision to intertwine his story with the life of trees came up during the conceptualisation process," Antony tells *Cosmos*. "Bob Brown has

spent decades advocating for the protection of old-growth forests and an end to native forest logging – or more accurately, forest clear-felling."

Antony and Billiet chose to "cast" three specific Tasmanian trees as Brown's co-stars: a *Eucalyptus regnans* in the Styx Valley, a Huon pine on the Picton River in the Southwest forests, and a Tasmanian myrtle in the Tarkine rainforest.

"Laurence and Rachael came and asked, 'would I [agree to the documentary]?' Brown said in an interview with RMIT University, "and the hook of course was the big trees, because we're okay but they're not."

"By intertwining the chronology of a tree's life with that of Bob Brown," Antony says, "we hoped to show how much we have in common, how our fates are intertwined."

However, the filmmakers quickly realised that trees are not the most visually engaging subjects to sustain a 113-minute movie.

"Trees are quite difficult to film as they are static and the most interesting part is often out of frame, up in the canopy," says Billiet. "We needed to think about a new way to bring the forest to life."

Their solution: dazzling pointillist-style animations, constructed using real LiDAR data.

While Bob Brown, below, is the human focus of *The Giants*, the filmmakers wanted find new ways to show the forests that Brown has spent his life fighting for.



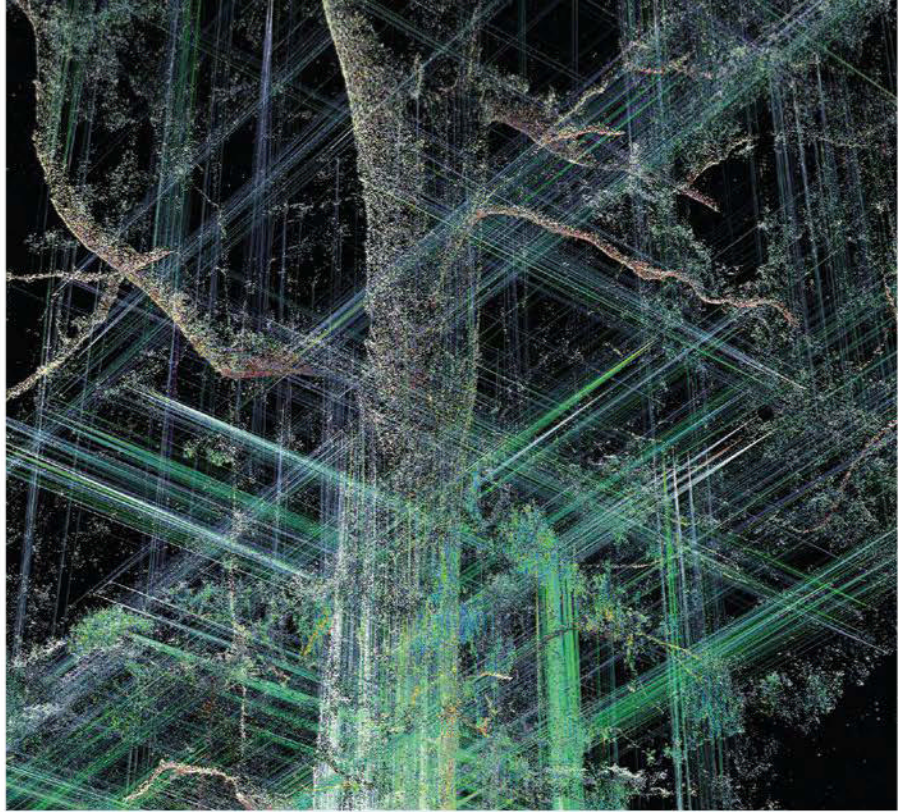
OUT OF THE FOREST, INTO THE FILM

While *The Giants* primarily uses comprehensive archival footage to present Bob Brown's life, its most memorable scenes are stunning animations of trees seemingly constructed from points of light. These images serve several purposes, from animating the movement of water through a plant, to showing the interconnected systems beneath the soil, to providing a ghostly visual highlighting the loss of these trees.

The sequences were created from LiDAR scans of real trees. LiDAR – or Light Detection and Ranging – is a method of data collection that uses laser pulses to measure distances remotely. LiDAR systems work by sending out laser beams, timing how long it takes for them to hit a surface and reflect back, then using the speed of light to determine the distance to the surface. By using multiple lasers to collect thousands of data points, researchers can form a three-dimensional scan of a given area – such as a forest.

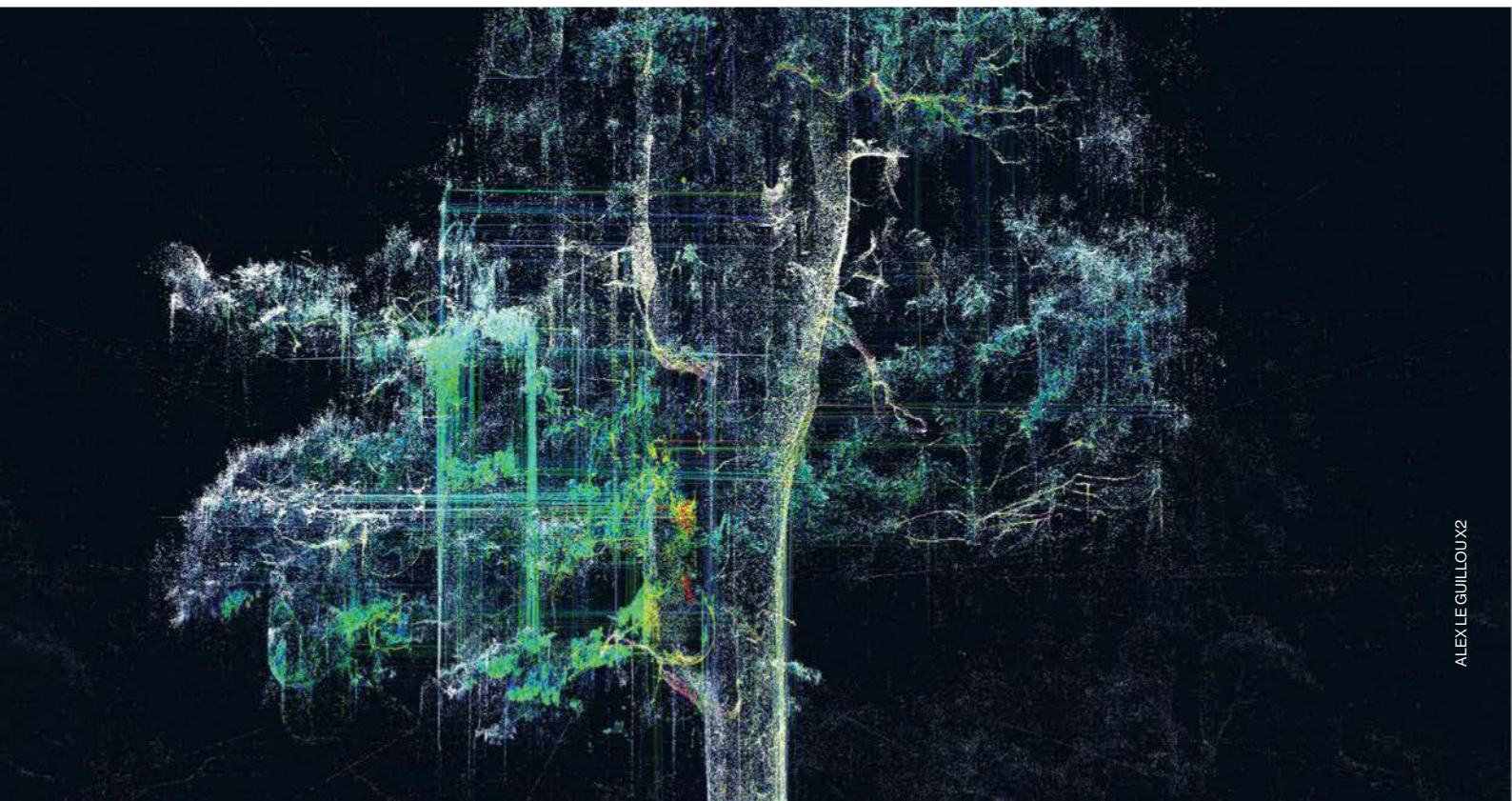
“Historically, foresters have used LiDAR to measure tree height and volume to predict growth,” says Leonard Hambrecht, a PhD student at the University of Tasmania (UTAS). “My current research involves using this technology to collect dense data in natural forests.”

Hambrecht is part of TerraLuma, an environmental remote sensing project at UTAS. It was one of the first groups in the world to publish research using high-resolution spatial mapping data of forests captured by LiDAR scanners mounted on drones. Among other things,

**“HISTORICALLY, FORESTERS**

TerraLuma uses LiDAR data to help monitor the impact of climate change on forests and to map plant life in remote areas.

“My research focuses on understanding the connection between the form and function of trees in native forests,” says Hambrecht. “From the high-point-density LiDAR data, I derive structural traits that have been found to be linked to tree function.”





USED LIDAR TO MEASURE TREE HEIGHT AND VOLUME”

Antony and Billiet first encountered TerraLuma’s work online while investigating LiDAR scanning in Tasmania. They asked whether the project would be willing to produce scans for *The Giants*’ animations.

“We had never worked with this technology before but we felt combining 3D scanning with actual cinematography was a good way to go past the limits of what our eyes can see, and paint a more evocative, whimsical portrait of the forest,” says Billiet.

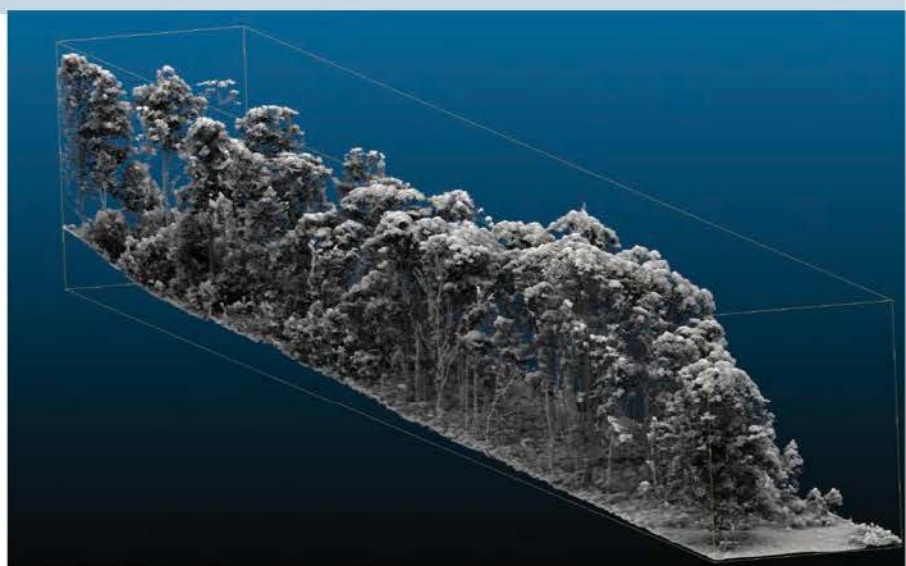
“We became interested in subverting this technology – which was developed for destructive industries such as logging and construction – for the opposite cause, to reveal the rich and hidden life of the forest and expose its wonder.”

SO, HOW DID IT WORK?

For *The Giants*, TerraLuma used a mix of drone and ground scanners, also called Terrestrial Laser Scanners (TLS), to capture the trees from the forest floor all the way to above the canopy.

“In the movie, you primarily see TLS data under the canopy,” says Hambrecht. “[The] TLS is mounted on a tripod and scans a 360-degree image with a built-in camera for colour information.”

This process takes several minutes; the large, cube-like scanner slowly rotates on its axis and sends out millions of invisible laser beams per second, while a central mirror rotates horizontally to adjust the lasers’ vertical orientation.



TerraLuma researchers found working with the filmmakers a rewarding experience. “One satisfying aspect for me is that this data is used to convey a visual story instead of solely for academic papers,” says TerraLuma’s Leonard Hambrecht.

“To create a 3D scan, we move the scanner five to 10 metres to the next location, depending on vegetation density,” Hambrecht explains. “After collecting several scans, we download them to a computer. The software aligns and stitches them into a large point cloud.”

Billiet and Antony asked TerraLuma to focus on scanning the three specific trees they had chosen. Yet even with just three subjects, the comprehensive nature of LiDAR scans meant that several hundred gigabytes of data were produced.

This mountain of data was then sent to French animator Alex Le Guillou, who was given the task of creating *The Giants*’ arresting animations.



FROM DATA TO ART

“Personally, I like to be inspired by tools from the world of science to create my visuals,” says Le Guillou. “For example, I’ve always been fascinated by the way traffic is represented by autonomous vehicles or the interfaces of surveillance systems. It’s really about the way technologies represent our reality.”

Le Guillou gathered the LiDAR data from TerraLuma, then categorised them according to the scenarios and visual features he wanted to convey. Though the scans were already three-dimensional forest landscapes made of dots, Le Guillou had to convert the point clouds to a format that his graphics software could use.

“To do this, I sometimes had to search for specific trees in these digital twins of the forest, and apply cropping and optimisation operations in order to interpret them graphically,” he says.

Le Guillou designed *The Giants*’ animated sequences using tools for creating visual effects in real-time, employing techniques typically seen in video games or live broadcasting. In doing so, he had to consider not only the locations, natural processes and emotions the filmmakers wished to portray in each segment, but also how

Animator Alex Le Guillou created 85 separate sequences at 4K resolution for the filmmakers to choose from.

to match the animations to the narrative of the sequences they would be placed in.

“Our aim was to divert this [LiDAR] capture technology to create contemplative sequences and propose a new way of observing these gigantic trees,” says Le Guillou.

Antony and Billiet filmed the same trees that TerraLuma scanned, enabling them to switch from animation to live action in the documentary. This also allowed Le Guillou to refer to their footage when creating his animations, including as reference for shading and lighting.

“I was able to analyse and draw inspiration from the sequences shot in real life to match the [computer-generated] sequences as closely as possible in terms of colour, camera speed and general atmosphere,” says Le Guillou.

“IT’S ABOUT THE

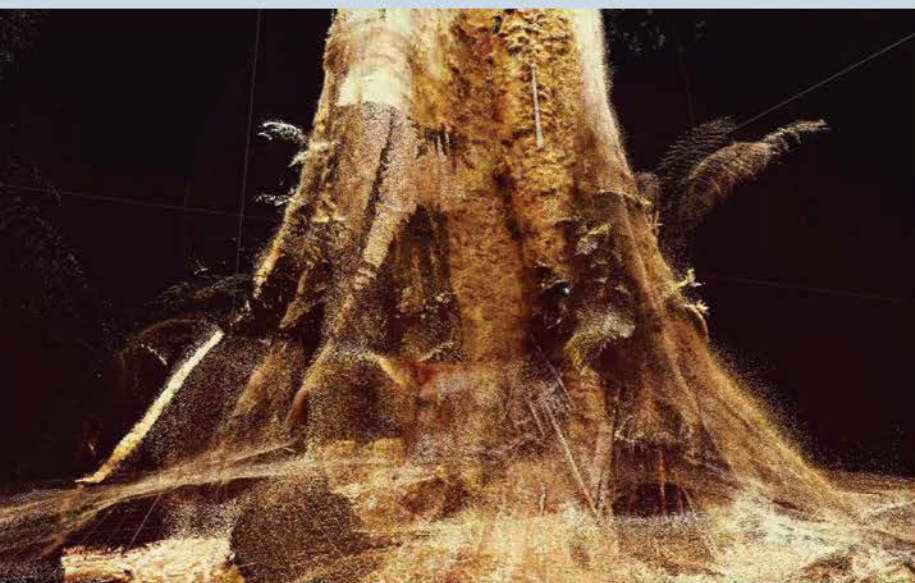
SEEING THE TREES FOR THE FOREST

While LiDAR can provide an incredibly detailed picture of the forest, some artistic interpretation was still required to bring TerraLuma’s scans to the screen.

The biggest obstacle was the sheer amount of data which, in a reversal of the classic idiom, made it difficult to see the trees for the forest. Though Le Guillou didn’t distort the LiDAR data, he made a variety of adjustments so the audience could make out the images more easily – for example, by displaying fewer data points in the background of an animation to ensure the focal tree’s denser points would make it more prominent. Depending on the scene, he also chose to make the environment more or less abstract.



WAY TECHNOLOGIES REPRESENT OUR REALITY."



Le Guillou was also asked to illustrate functions that LiDAR scans can't capture.

"For *The Giants*, the use of 3D scanners was a way of breaking free from the limits of human observation and going further in the observation of these giant living organisms," says Le Guillou.

"The manipulation of point clouds allowed me to propose unique points of view impossible with traditional cameras, like navigating inside the tree or under the ground."

He created animated interpretations of natural processes such as water rising through a tree, the intertwining of underground fungal and root systems, and the raging of a bushfire featured in the opening scene. Animation also allowed *The Giants* to construct footage such as the top of a

The trees that TerraLuma scanned were filmed by the documentary makers to allow them to intertwine real and animated forest areas into a single sequence.

forest canopy, which was too high for traditional cameras to reach.

"One of the great advantages of 'scan world' is that we had more freedom to create virtually any shot we wanted within the scanned area – provided there was enough data – so it allowed us to show things that we couldn't film," says Billiet.

BRANCHING TO THE FUTURE

Some of *The Giants*' most haunting animations are its ephemeral white trees, drawn in sparse pointillism that seems delicate enough to be threatened by an uncaring breeze. The documentary's LiDAR graphics effectively illustrate the danger these giants are in, while remaining grounded in science.

"Anecdotally, some people think the animation is CGI – they are pretty surprised when we explain that the animation is drawn from LiDAR scans of actual trees," says Antony.

"While *The Giants* is not a scientific film per se, incorporating scientific expertise, as well as techniques such as LiDAR scans, brought additional layers of complexity to the film.

"I think Australians have a real appetite for science and how it can help them understand our natural world." 🌿

AMANDA YEO is a Sydney-based technology writer. Her last story for the magazine, on holographic concerts, appeared in Issue 94. Find out where to stream *The Giants* at www.thegiantsfilm.com/watch-the-film



The colour, the fruit, the butterfly's wing, the flash of sun in a rock or the glow of the infant universe... **Ashley Hay** illuminates the history of a narrow band of wavelengths that may have made us human.

It's a spring night in south-east Queensland, just before the rising of a slightly waning moon. A group of us are sitting in a field around the bright glow of a fire pit (no bans tonight) – adults, teenagers, dogs. We pass around snacks; we pass stories as well.

The fire's orange plays beneath this darkness, softening what we can see of each other's features in the same way this holiday has softened the speed at which we're living for a while and made it possible to see what's underneath our normal pace.

For American anthropologist Polly Wiessner, firelight provided a crucial impetus for the human work of storytelling. Through time spent with the Ju/'hoansi (the !Kung bushmen of Botswana and Namibia) across more than four decades, Wiessner explored changes brought about by human control of fire on 'anatomy, social and residential arrangements', looking past the impact of fire on cooking to its impact on social activities and the development of human imagination.

Where earlier hypotheses suggested that stories grew out of a need to share information about resources, Wiessner focused on their function in terms of people understanding other people; of people finding ways of talking that stepped beyond the requests and negotiations that mark out a day's work; and of people developing empathy. As she writes in a seminal 2014 *PNAS* paper:

"Stories told by firelight put listeners on the same emotional wavelength, elicited understanding, trust, and sympathy, and built positive reputations for qualities like humour, congeniality, and innovation. The capacity for expanding the imagination by night may have deep roots, extending back to the regular use of

fire in encampments some 200,000–300,000 years ago, a time when evidence for broader intergroup interactions begins to crop up in the archaeological record."

There's now evidence to suggest that the flickering of fire not only sparked the growth of our imagination but also impacted the scope and aspiration of artistic output. Recent research on the Upper Palaeolithic plaquettes of Montastruc, France – portable stones engraved with images of creatures including a mammoth and a swimming reindeer – suggest that these were displayed close to fires, which essentially animated the figures.

In "Art by Firelight", published in *PLOS One* in 2022, Andy Needham and his team describes how "the interaction of engraved stone and roving firelight made engraved forms appear dynamic and alive, suggesting this may have been important in their use. Human neurology is particularly attuned to interpreting shifting light and shadow as movement ... with the dynamic light cast from a hearth bringing the depictions to life."

The timing of human control of fire is widely – one could even say hotly – debated: estimates range from 1.6 million years ago to much more recent eras. But how far back can the colour of firelight take us? How far does that orange glow go?

BETWIXE YELOW AND REED

The relationship between white light and the visible spectrum is a well-told story in Western science. The colours of the spectrum are called out in various songs and nursery rhymes: red, orange, yellow, green, blue, indigo, violet. But the specific inclusion of orange required a critical cultural and historical element on top of the scientific observation that split white light into brilliance.

The science was realised in 1672, when Isaac Newton published his first major paper, "...Containing His New Theory about Light and Colors", in the Royal Society's *Philosophical*

Transactions. It describes experiments he had begun in the previous decade: “having darkened my chamber, and made a small hole in my window-shuts”, Newton allowed a beam of light to pass through a glass prism, a child’s toy that he had bought at a fair. From this came his seminal observations of the splitting of white light into a spectrum of component colours – and he named five. Red. Yellow. Green. Blue. Violet.

Three years later, in *Lectiones Opticae*, Newton requantified the spectrum required to make white light so that it contained seven elemental colours – adding orange and violet. One Newtonian biographer, Patricia Fara, describes this as him allowing rainbows to “conform to his Pythagorean vision of a harmonious universe whose mathematical characteristics corresponded with the seven notes of the musical scale”. Newton himself delineated this recast spectrum as “the original or primary colours [of] Red, yellow, Green, Blew, & a violet purple; together with Orang, Indico, & an indefinite varietie of intermediate gradations”.

But this fundamental understanding that white light is “the most surprising and wonderful composition” required the recent arrival of the word *orange* in the English language.

Because before this, the colour was known in English as yellow-red. As Yale University’s David Scott Kastan and the artist Stephen Farthing note in their collaboration *On Colour* (2018), until oranges arrived in Europe from the east, “there was no orange as such in the colour spectrum”:

“When the first Europeans saw the fruit they were incapable of exclaiming about its brilliant orange colour. They recognised the colour but didn’t yet know its name. Often they referred to oranges as golden apples. Not until they knew them as oranges did they see them as orange.”

The first recorded mention of orange as a colour relates to clothing purchased for Margaret Tudor, Henry VIII’s sister and later the Queen of Scotland, in 1502 – a scant century after Chaucer, in “The Nun’s Priest’s Tale”, had to describe a rooster dreaming of a fox whose “color was betwixe yelow and reed”. This literary palette-mixing was his best option in the 1390s.

Once oranges had arrived from India and became more common and visible in markets and kitchens, “the name of the fruit [provided] the name for the colour”. Within decades, Kastan and Farthing point out, “people could imagine that the

fruit was called an orange simply because it was”. Which gave Newton the colour-name to include in his revised seven-part spectrum in 1675. Even now, orange remains distinct as a colour whose few English synonyms stand for objects as much as hues. Think tangerines. Think apricots. Its semantics set it apart.

IN THE FIRST CRUCIBLE

Though only a recent arrival in the English language, orange was one of the earliest colours to emerge in the evolution of the universe.

The Big Bang was not some blinding flash of light so much as an expanding space filled with energy. As US astrophysicist Brian Koberlein explains:

“At first, temperatures were so high that light didn’t exist. The cosmos had to cool for a fraction of a second before photons could appear. After about 10 seconds, the universe entered the photon epoch. Protons and neutrons had cooled into the nuclei of hydrogen and helium, and space was filled with a plasma of nuclei, electrons and photons. At that time, the temperature of the universe was about one billion degrees Kelvin.”

It took another 380,000 years for the universe to cool enough for these nuclei and electrons to bind into atoms, allowing what we call “colour” to emerge. By which time, Koberlein says, “the observable universe was a transparent cosmic cloud of hydrogen and helium 84 million light-years across”. It registered a temperature of 3,000 degrees Kelvin, giving it “a bright orange-white glow, similar to the warm light of an old 60-watt light bulb” – or “an orange glow similar to firelight”. Always a good place, fireside, to start a story.

And so, for the first few million years of its incarnation, the universe itself was orange.

MONARCHS TO MINERALS

Orange has proliferated across Earth’s natural world, from the startlingly solid avian brilliance of the

Guianian cock-of-the-rock (*Rupicola rupicola*) to sunstone or heliolite, a type of feldspar whose sunlike flashes of light come from traces of copper, hematite or goethite embedded “parallel to one of the crystallographic planes within the stone”.

Orange is also particularly common in butterflies, from the famous migrating monarchs and Gulf fritillaries of the Americas



“STORIES TOLD BY FIRELIGHT

PUT LISTENERS ON THE SAME

EMOTIONAL WAVELENGTH.”



(and beyond), through butterflies on all the continents, on to one of Australia's most endangered butterfly species, and one that is just settling in.

The Australian fritillary – *Argynnis hyperbius inconstans* – has a 94% likelihood of becoming extinct by 2040. These fritillaries begin life as “jet black caterpillars with a vibrant orange racing stripe and large spikes along their backs”, transforming into “stunning orange and black butterflies”.

According to 2021 media reports of Australia's projected butterfly extinctions, no one had managed to collect or photograph an Australian fritillary this century, “although a butterfly expert observed a single individual flying near Port Macquarie in 2015”.

By comparison, the tawny coster (*Acraea terpsicore*, originally an inhabitant of India and Sri Lanka) reached Australia in 2016, rapidly establishing itself from Broome to Groote Eylandt and expected to move further into the country's north-east. This is only Australia's third known butterfly incursion, after the white cabbage moth in the 1920s and the monarch in the 1870s.

Natural orange colour – the orange of pumpkins, sweet potatoes and oranges themselves, as well as birds' feathers and butterflies' wings – come from carotene: orange-red photosynthetic pigments that are one of four carotenoids. Like chlorophyll, these pigments can convert sunlight into chemical energy. They take their name from the colour of the carrot – a colour they provide – in which they were first discovered in 1831.

But oranges (the fruit) had been involved in an earlier scientific study. In 1747, in the world's first clinical trial, Scottish physician James Lind explored the efficacy of oranges and lemons in preventing scurvy amongst sailors. Despite sailors being given citrus juice shortly thereafter, the connection between scurvy and a vitamin deficiency wasn't identified until 160 years later in 1907. Subsequent vitamin C research by Norman Haworth and Albert Szent-Györgyi saw them receive the 1937 Nobel Prize in Chemistry and in Physiology or Medicine respectively.



“ORANGE WAS ONE OF THE EARLIEST COLOURS TO EMERGE IN THE UNIVERSE.”



Orange is not just limited to the fruit – it appears throughout nature, for example in heliotite (above), monarch butterflies (below) and Gulf fritillary caterpillars (opposite).

Oranges remain the fruit most readily associated with this vitamin – despite the fact that several foods supersede them in the vitamin stakes, including Australia's Kakadu plum, *Terminalia ferdinandiana*, which boast levels a hundred times higher.

WINDOWS OF PERCEPTION


On that spring night, with the fire feeding all these stories, we people and our dogs settle, quieter, as the big moon rises, its warm orange obscuring so many of the night sky's other points of light.

It's still possible to find rich orange out there: one of the most recent pictures from the James Webb Space Telescope shows two actively forming stars,

Herbig-Haro 46/47, as a brilliant orange flash amongst the busyness of reds, pinks, blues and the great black blanket of space. These binary stars lie “close by”, as NASA describes it, 1,470 light-years away in the Vela Constellation. They will continue to form for millions of years.

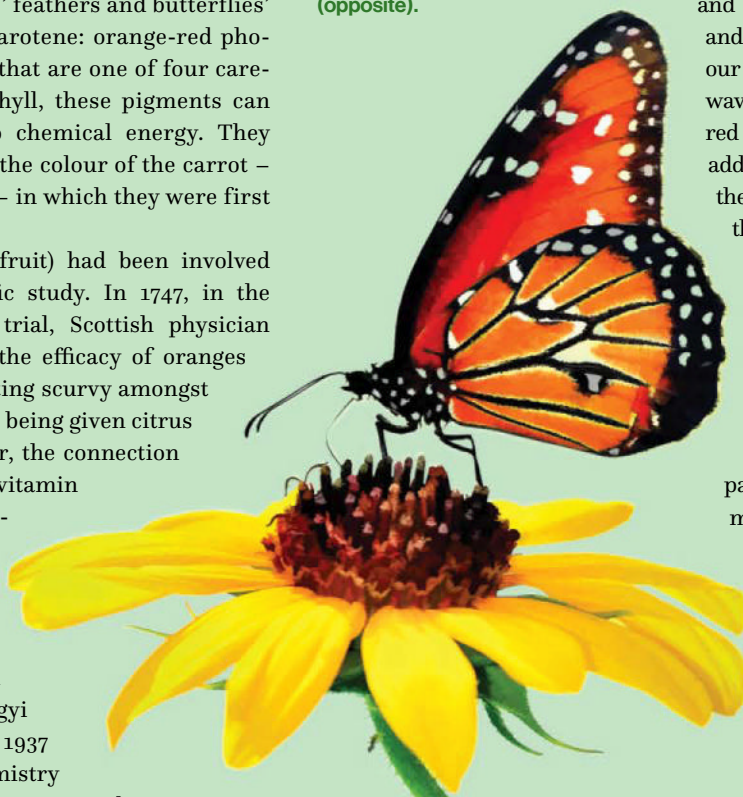
But are these stars' “rambunctious antics” really orange? James Webb is an infrared observatory – all of the light it detects is beyond light the human eye can see. And so colours are assigned to the different wavelengths when the images are processed. Astrophotographers, researchers and imaging specialists stretch, scale and clean up the data files and apply colour chromatically: blue for the shortest wavelengths; green for the mid-range; red for the longest, with the potential addition of “purple, teal, and orange” if the final image is made up of more than three files of information.

We're colouring the universe, tinting it to create awe-inspiring pictures. But we're also using colours to allow our narrow sight to perceive the complexity of the universe, transforming information into brilliant revelation. This palette changes how we understand a mass of mass and energy; it lets us see the universe – literally – in a different light.

The warmest orange, changing what we see and how we see it, as we recognise its glow. 

ASHLEY HAY is based in Brisbane.

Her story on the reefs of Lady Elliot Island appeared in Issue 99.



ELECTRIC DREAMS

When it comes to electric cars, what's fact and what's fiction?



Do electric car batteries explode?

As electric vehicles (EVs) become more common, they're raising plenty of questions and generating a few rumours – such as whether their batteries could catch fire or even explode.

Let's go back a bit. How do batteries actually work? Batteries perform a chemical reaction which releases energy in the form of electrons – or stores energy by putting electrons back in. The electrons flow through a circuit, allowing electricity to power your machine. But something else has to move through the battery to balance the electrons zooming through the circuit.

An EV battery uses lithium to do this job, which can store more energy by weight than many other materials (such as the lead used in a lead-acid battery). In cars, energy density is extra important – both so you're not lugging around too much weight, and so you can still fit a passenger or three in the car with you.

But lithium has its problems, including thermal runaway. The chemical reactions inside the battery, which make it work, can get out of hand, causing localised heating that can trigger a more significant event – such as catching fire.

However, it doesn't happen all that often, according to firefighter Emma Sutcliffe from EV FireSafe.

"It's a bit of a myth doing the rounds on social media that electric vehicles catch fire all the time," she says. "In fact, they're far less likely to catch fire than an internal combustion engine vehicle."

There's around a 0.0012% chance of a passenger EV battery catching fire. Internal combustion vehicles, on the other hand, have a 0.1% chance – 100 times more likely than an electric car.

Sutcliffe says that we have only had seven electric vehicle battery fires in Australia: "None have been spontaneous. There has always been human involvement to cause abuse to cells leading to thermal runaway and fire."

But another explosive battery-powered device has flown under the radar.

"Unfortunately, in the last 18 months that we've been tracking this data ... we've lost four whole families [globally] due to e-bike battery fires," Sutcliffe says. "Poor quality e-bike batteries [are] catching fire in people's homes, going into thermal runaway."

E-bikes and e-scooters don't have to adhere to any particular standards, she explains, while EVs must be road registered and comply with regulations and testing.

For example, if you're in an accident the cage surrounding the battery in electric cars is built to take a beating. Plus in some EVs the battery is built to fall out of the car if thermal runaway starts happening.

Lithium batteries can occasionally catch fire while charging, or after being damaged. They're prone to a process called thermal runaway: a chain reaction that happens inside the battery that releases heat.



“Even going across the Nullarbor is possible, if you factor in an extra day or two for charging time.”



Will electric cars ruin the weekend?

“I tell you what, it’s not gonna tow your trailer, it’s not going to tow your boat, it’s not going to get you out to your favourite camping spot with your family.”

According to former Prime Minister Scott Morrison in 2019, EVs would “end the weekend”. Is he right? To find out, we’re going to have to understand some EV specs.

Let’s start with torque. When you tap the accelerator in your EV, electricity from the battery flows to the motor, where it generates a magnetic field that turns a central rotor, thus turning the driveshaft. This forms part of the EV’s drivetrain – usually a single gear – which drives the wheels. The force causing the rotor to spin is called torque, and EVs have plenty of it. Torque is generated instantaneously and is consistent irrespective of rpm, which means EVs can do away with the need for multiple gears and revving up a big engine.

EVs have a high torque and power capacity, much more than most internal combustion vehicles. This is because EVs are efficient – around 80% of the energy stored in the battery is actually translated into the movement of the wheels, while the best combustion engine gets about 30% efficiency.

This means these cars are easily capable of pulling a heavy trailer. And as companies are redesigning the vehicle from scratch around an electric motor to make EVs even more efficient, we’ll see more improvements in towing capacity and torque.

What about range? The few dozen electric vehicles on the market today have fully-charged range estimates spanning from 400 to 600 kilometres. If you’re going to a major country town for the weekend, there’s no problem – chargers are being added to the network all the time, included ultra-rapid ones. Unless you’re going a long way off the grid, you’ll be fine. Even going across the Nullarbor is possible, if you take an extra day or two.

Four years on from Scott Morrison’s comments, the world of EVs is very different. The increase in charging infrastructure means you can make long trips across state borders with relative ease, as long as you plan your stops a little more carefully.

Still, a 45-minute charge gives a good opportunity to stretch the legs and grab a lamington.

Are electric cars actually more sustainable?

Some claim that if you're not running an EV on renewable electricity, they're worse for the environment than petrol and diesel cars.

Let's see if there's any weight to the rumour. You might assume that if you're running an electric vehicle on grid electricity, it's only going to be as clean as the grid it's running from. Given that the majority of Australia's electricity still comes from fossil fuel sources, what does that mean for vehicle-linked emissions?

Well, they're still lower in most situations, according to Jennifer Rayner, head of advocacy at the Climate Council.

"There's research that indicates that even if you're powering an EV from the grid, which might be using a mix of power sources, that is still significantly cleaner than driving a petrol car, which is spewing out the emissions associated with its internal combustion engine," she says.

Rayner cites the International Council on Clean Transportation's assessment of vehicle lifecycles, which found that EVs have "by far" the lowest life-cycle greenhouse gas emissions. In the US and Europe, EVs were 60–70% cleaner than comparable conventional cars, while in India and China, with more coal-dependent grids, they were 19–34% and 37–45% cleaner, respectively.

It's also worth noting that all of these statistics are changing fast – particularly in Australia.

"At the moment, we're basically literally seeing the grid get cleaner by the day," says Rayner.

In 2022, 32% of Australia's total energy was generated from renewables, up from 29% in 2021. Renewable energy varies significantly by state: Tasmania and the ACT ran on 100% renewables (or close to it), while only 6% of the NT's energy mix was renewable.

What about other emissions associated with electric vehicles? "It's absolutely true that the production process for manufacturing EVs mean that it can produce something like 80% more emissions in the manufacturing process than an equivalent petrol car," says Rayner.

Those extra emissions come primarily from the battery, made from precious metals like lithium, nickel and cobalt that take energy to mine.

"But over the lifecycle of a vehicle, the vast majority of the emissions come from driving it around," says Rayner – and EVs win on that front, even when charging off a grid that is still reliant on coal and gas.

But drastically reducing transport emissions doesn't need to involve cars at all. "To cut emissions by 75% by 2030 ... we'd need to roughly halve the number of trips that Australians make by car and see a massive uptake in active transport," Rayner says.



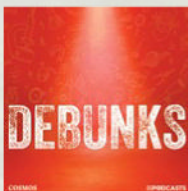
At around 75% capacity, batteries can no longer be used in EVs, but can be recycled into other applications.



“If you’re not running an EV on renewable electricity, are they worse for the environment than petrol and diesel cars?”



To dive even deeper into EV science, listen to our new podcast *Debunks*.



Can electric vehicle batteries be recycled?

Just 10% of Australia’s lithium-ion batteries were recycled in 2021, compared with 95% of lead-acid car batteries. But we’re going to have many more batteries to deal with over the next decade. Experts estimate we will have 1.6 million tonnes of EV batteries to recycle in Australia by 2050.

So how easy are EV batteries to recycle? Let’s start small. Don’t do this at home, but imagine you cut open a lithium rechargeable AA battery.

Inside you’ll see a mix of lithium, nickel, cobalt and manganese – all valuable and often rare materials. This little battery we’ve just mangled is called a cell.

EV batteries are made of the same components, but they’re slightly more complicated in structure.

“You won’t have just thousands of cells floating around – you might have them subdivided into packs,” says Katharine Hole, CEO of the Australian Battery Recycling Initiative. “Between those packs, you might have electronics, or a battery management system – they all monitor things like temperature or faulty cells.”

But they can still be recycled, just like smaller batteries.

“The processes we use to recover the minerals out of a battery are exactly the same as recovering a mineral out of the rock,” says Hole.

Small lithium batteries are “just put through a big shredding machine”, which produces a black mass from which individual elements can be separated. Two processes are used: hydrometallurgy uses a series of chemical solutions to extract each of the metals, while pyrometallurgy uses high temperatures to do the same.

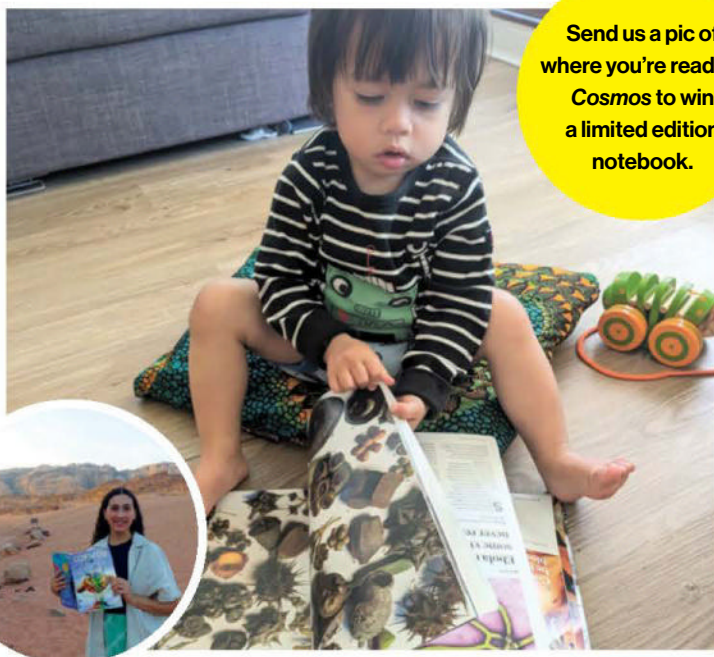
Bigger EV big batteries can’t go straight into a shredder: they need to be disassembled, separating the casing and electronics from the cells, with each going down different recycling routes.

But there are some challenges to EV battery recycling, especially if the battery is damaged from an accident. Hole says there’s research into using robotics and artificial intelligence for the “safe disassembly, because clearly you’re dealing with batteries with very high voltages”.

EV batteries also don’t have to go straight to the shredder: they could be used in other applications, such as home battery storage, once they’ve run down too much to be usable in cars. ☺

JACINTA BOWLER & ELLEN PHIDDIAN are *Cosmos* journalists. Our new podcast, *Debunks*, uses science to bust myths ranging from EVs to weight loss to bushfires.

WHERE IN THE COSMOS?



North meets south

This made our week: 20-month-old Sebastian is paging through a classic. According to his parents, Issue 93 from December 2021 contains all his favourite things – trees, astronauts and robots (see his t-shirt). Meanwhile, Sylvia took her copy of our “Reasons to Hope” issue to Wadi Rum in Jordan. We’d love to see where you’re reading. Send us your shot: contribute@cosmosmagazine.com.

GUESS WHO?

Question

Whose Law?

Decode where a = ☞

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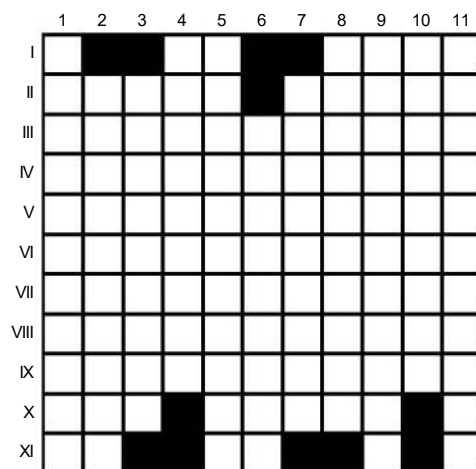
Hint: The original statement was published in French in 1855.

MIND GAMES

NO27

Who Said?

“The ocean’s bottom is at least as important to us as the moon’s behind.” (6,1,4)



Instructions

Answers to each of the clues in columns 1 to 11.

Row VIII reveals the answer.

Clues and columns

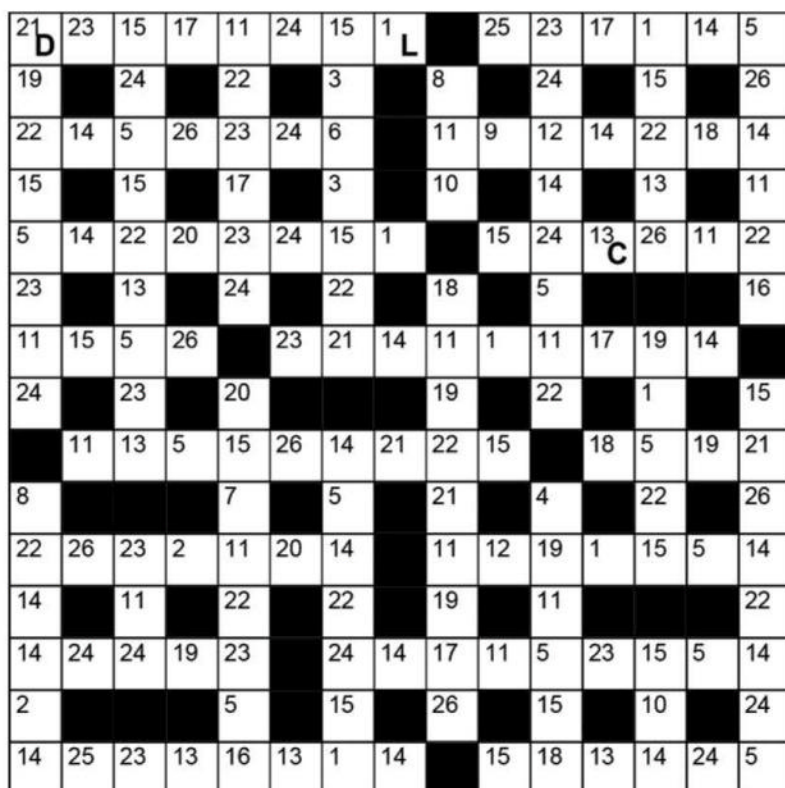
- Which type of scientist studies freshwater lakes and ponds? (11)
- What is the coagulation of the blood, blocking veins or arteries? (10)
- In which city are the world class science museums Camera Obscura, Surgeons' Hall and Dynamic Earth? (9)
- The Great Square of Pegasus is formed by three stars of Pegasus and the brightest star of which other constellation? (9)
- What was created by an engineer as the centrepiece of the Paris Exposition of 1889? (6,5)
- Which predatory flying insect, of the infraorder *Anisoptera*, lives in every continent except Antarctica? (9)
- First funded by the sale of Second World War military surplus, which US-Australian university scholarship is named after a US senator? (9)
- Who created a series of paradoxes, including 'Achilles and the Tortoise'? (4,2,4)
- What was the initial name given to the human skeletons, of the Upper Palaeolithic period, found in 1901 in caves near Ventimiglia, Italy? (8,3)
- From the Spanish for "little armoured ones", what are the New World mammals of the order *Cingulata*? (9)
- What is the branch of physiology concerning secretions? (11)

COSMOS CODEWORD

NO27

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, 'A' might be 6 and 'G' might be 23.

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.



1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

ALL PUZZLES DESIGNED AND COMPILED BY SNODGER.COM.AU

IT FIGURES

NO27

	1	2	3	4
A				
B				
C				
D				

Instructions

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

Level 1 – Chief Scientist

- 1 The difference between any two adjacent numbers is always prime.
- 2 The number of digits in Column 3 is twice that of Column 1.
- 3 Only the last number in the down sloping diagonal is not a factor of 16.
- 4 Row A ends with two multiples of 5 and has a sum of 29.

Level 2 – Senior Analyst

- 5 The smallest number is in a corner.
- 6 There are two multiples of 7 in the bottom row.

Level 3 – Lab Assistant

- 7 The product of the first two numbers in Row B is 48.

SOLUTIONS: COSMOS 100

CODEWORD



IT FIGURES

16	1	13	4
9	12	6	15
5	8	2	11
10	7	3	14

WHO SAID?

Jane Goodall

The English primatologist and anthropologist is considered the world's foremost expert on chimpanzees, and works extensively on conservation and animal welfare issues.



WHOSE LAW? ANSWER:

When gases chemically react together, they do so in volumes which bear small whole-number ratios, provided that the temperature and pressure of the reacting gases and their products remain constant.

Gay-Lussac

Xavia and Marley Furner

Young conservationists



At 11 and nine years of age, Xavia (left) and Marley (right) Furner have seen more of Australia than most adults. Growing up in Far North Queensland, their playground was the sea, their favourite activities snorkelling and free diving.

When COVID hit, the family decided to travel for a year. During this trip around Australia, Xavia and Marley discovered a deep curiosity for nature, and now they consider themselves keen adventurers and environmentalists. Who else swims with whale sharks before hitting double digits?

Today the two siblings live in a small coastal community in Tasmania. Their house sits on a point surrounded by sea, and some of their closest neighbours include a critically endangered species, the red handfish (*Thymichthys politus*).

“My favourite part of the red handfish is the pompom on its head,” Xavia says. “It

looks like a light bulb, like it’s always having good ideas.”

“I love their frog hands,” Marley says. “Sometimes I think, how in the world did nature just make this happen?”

Marley feels some sadness when he thinks of this tiny species. He has a great life on the coast, and it upsets him that just down the road, the fish might be struggling.

Both Marley and Xavia are so passionate about helping the species that they turn up to every meeting of the community group – Friends of the Red Handfish – often with a long list of questions and suggestions.



For now, they’re dedicated to raising the profile of this strange creature. “We need more people to know and care about them. When an animal is so rare you’ve got to act now or never to save it.”

READ ABOUT THE FRIENDS OF THE RED HANDFISH ON PAGE 74.

“

Sometimes I think, how in the world did nature just make this happen?





**Going bush,
to tell stories
from across the nation
about the people,
places and industries
facing climatic change
and innovating
to confront it.**

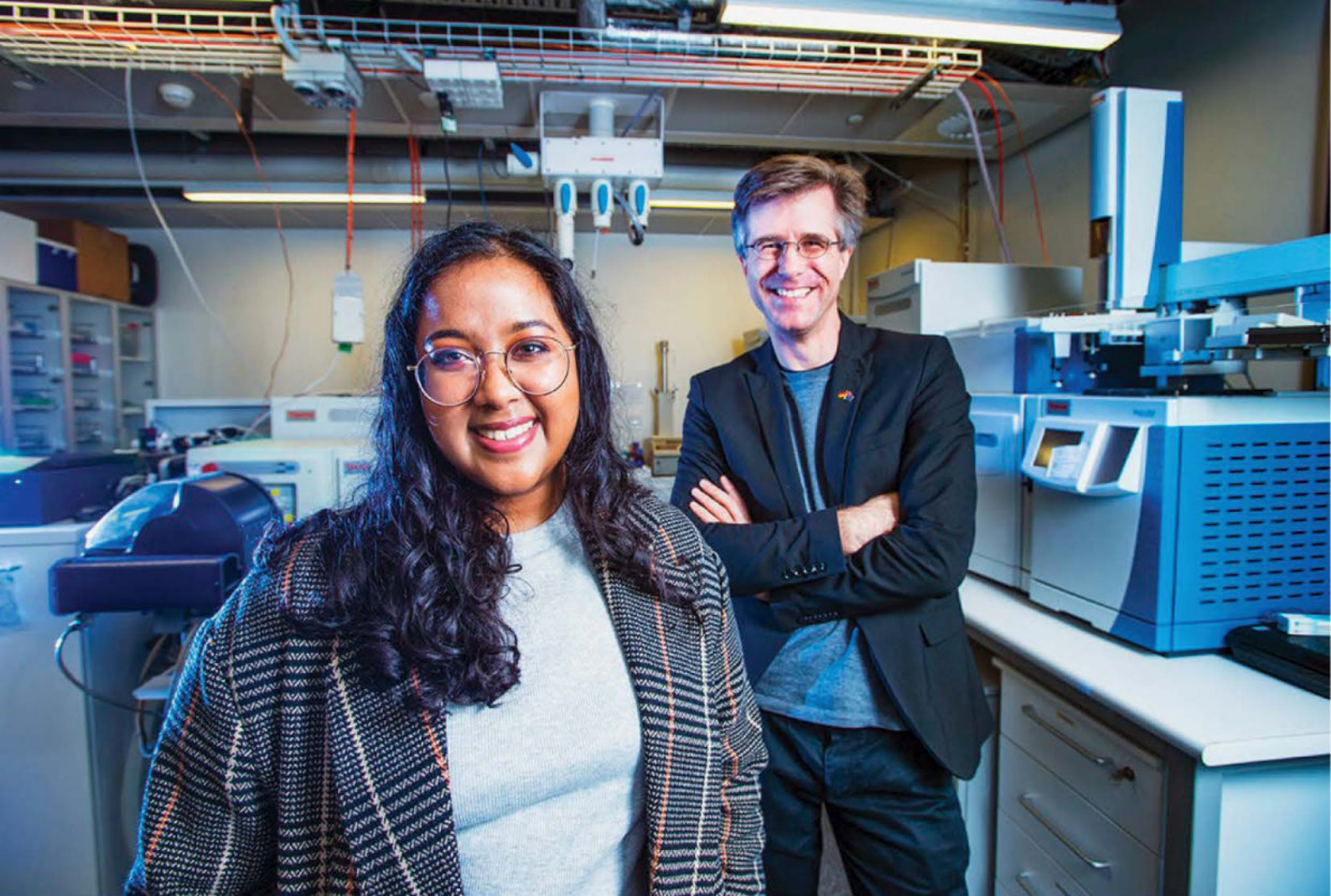
Please join us – there's much to learn.

[**cosmosmagazine.com/Greenlight-Project**](https://cosmosmagazine.com/Greenlight-Project)



GOT A STORY?
Give us a shout at
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Are you an independent and original thinker seeking your next challenge?

QUT PhD student **Ishrath Irshadeen** works with ARC Laureate Fellow **Distinguished Professor Christopher Barner-Kowollik** on pioneering research, using light-induced chemical reactions to develop polymeric materials for catalysis, making the world a more sustainable place.

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